June 2004

Benefit-Cost Evaluation of a Highway-Railroad Intermodal Control System (ICS)

Prepared for Alstom/NYSDOT/FHWA/FRA

Abstract: Improved train location information and vehicle detection combined with grade crossing controls, traveler information, and traffic management can improve safety and reduce delay for both passengers and vehicles. In addition, the possibility of pre-empting the crossing for emergency vehicles, when it is safe to do so, may save lives and hasten medical recovery. The ICS project, designed for a suburban commuter station on the Long Island Rail Road, is unique in controlling both vehicles and trains, to the ultimate benefit of both. The project has not been deployed, so the evaluation is based on impacts estimated from characteristics of the design and the setting.

U. S. Department of Transportation
Volpe National Transportation Systems Center
Cambridge, MA

Authors:	Douglass B. Lee, Jr. 617/494-2762 LeeD@volpe.dot.gov Kevin Gay Anya A Carroll Adrian Hellman Suzanne Sposato

Contents

Executive Summary ix
  Performance Requirements. ix
  Impacts of the ICS x
    Train Operations x
    Vehicle Traffic xi
    Accident Frequency xi
    Accident Severity xii
    Variable Message Signs xii
    Stalled Vehicles. xii
    Emergency Preemption xiii
    Local Traffic Management xiii
  Estimated Net Benefits xiv
    Prototype Scenarios xiv
    Benefits by Action and by Type of Benefit xiv
    Incremental Benefits of Separate Actions xv
  Costs xvi
  Conclusions xvi

Project Description 1
  System Performance. 1
  Technology Components and Information Flows 3
    Automatic Train Control (ATC). 3
    Intelligent Grade Crossing Controller (IGC) 4
    Intelligent Traffic System (ITS) 4
  Evaluation Framework 5
    Base Case (without the ICS) 6
    Improvement Alternatives 7
    Expected Impacts 7

Impacts of ICS Deployment 9
  Constant Warning Time. 9
    Impacts from Train Position Information 9
    Reduce Excess Gate Down Time 10
      Automatic Train Control versus Block Control.. 11
      Through Trains 11
      Trains Stopping at a Station 12
      Deceleration. 12
      Dwell Time at the Station 13
      Acceleration. 13
      Gate Down Time per Closing 13

Trains per Year 14
Reduce Vehicle Delay 15
Vehicle Traffic Queuing 15
Additional Delay From Two-Train Events 16
Frequency of Two-Train Events 17
Validation from Field Data 18
Reduce Train-Vehicle Collisions 19
Accident History 19
Accident Prediction Models 20
DOT Model 21
Prevent Transient Gate Openings 23
Reduced Collisions 23
Additional Vehicle Delay 23
Effectiveness Rates 24
Accident Severity 26
Unit Costs of Collisions 27
Provision of Status Information via VMS 30
Change Driver Behavior 30
Change Pedestrian Behavior 30
Detection of Stalled Vehicles 32
Reduce Collisions 32
Reduce Emergency Stops 33
Emergency Vehicle Preemption of the Grade Crossing . 33
Preemption Procedures 33
Delay Savings for Emergency Vehicles 35
Costs to Train Passengers 36
Local Traffic Management 36
Local Traffic Problems 37
Intersection Redesign 41

Synthesis and Conclusions 43

Aggregation of Benefits 43
Mapping of Actions into Benefits 43
Methodology 44
Prototype Scenarios 44
Benefits by Type of Benefit 46
Vehicle Delay 46
Collision Reduction Benefits 47
Benefits Tabulated by Action 48
Full Deployment 48
Benefits Cross-Tabulated by Action and Benefit 48
Incremental Implementation 49
Alternative Ways to Obtain Benefits 50
Vehicle Delay Savings 50
Collision Reduction 51
Costs and Benefits 52

Costs 52
Net Benefits 52
Distribution of Benefits 54

Appendix A: Study Background 57

Other Studies of Grade Crossing Technology 57
GRS/Alstom Contract 57
Project Deployment Evaluation 57
ICS Study Participants. 58
Operation 58

Appendix B: Train Speed Models. 59

Constant Velocity 59
Constant Acceleration 60
Clearing the Island Circuit 61
Through trains traveling at less than the maximum speed 61
Variable Acceleration and Deceleration 61
  Acceleration. 61
  Deceleration. 63

Appendix C: Vehicle Queuing Models 67

Two-Train Events 67
Total Delay and Maximum Queue Length 68
Frequency of Two-Train Events. 69

Appendix D: Valuation of Travel Time 71

Theory of Travel Time Valuation 71
Vehicle Travel Time 72
  Vehicle Occupants 72
  Average Vehicle Occupancy. 72
  Vehicle Costs 73
  Inventory Costs. 75
  Personal-Use Percentage of VMT 75
  Distribution by Vehicle Class 75
  Average Value of Time per Vehicle 76
Train Passenger Time 76
Emergency Vehicle Time. 77

Appendix E: Accident Frequency/Severity Models . 79

Accident Frequency Modeling 79
Crossing-Specific Risk Factors 79
Risky Behavior 80
Reduce Gate Violation. 80
Incremental Treatment Impact 81

DOT Model 81
Canadian Model 82
Negative Binomial Model 83
Comparison of Risk Prediction Models 85
Accident Severity Model 86

Appendix F: Variable Message Sign Effectiveness . 89

VMS Effectiveness. 89

Appendix G: Constant Warning Time Technology . 91

Grade Crossing Predictors 91
Communications Based Train Control (CBTC) 92
Custom Solutions 93
    Axle Counter Systems 93
    Wayside Magnetometer 95
    Doppler Radar System 96

Appendix H: Vehicle Detection Technology . . . 97

Inductive Loop Detectors. 97
    Specifications 98
    Costs 98
Microwave Radar 98
Wireless Video 98

Appendix I: Preemption by Emergency Vehicles. . 101

Purposes and Methods of Preemption 101
Current Emergency Vehicle Activity in New Hyde Park 101

Appendix J: Facilitating Local Traffic With ITS . . 105

Increase Throughput 105
Reduce Delay to Non-Crossing Traffic 105
Other Strategies for Moving Blocked Traffic 106

References. 107

Acknowledgements

Many people helped the authors in numerous ways over the several-year course of the study, some of whom are named below:

Steve Diana, Long Island Rail Road
Seth Edelman, New York State Department of Transportation
Darlene Ferrer, formerly Long Island Rail Road
Ray Ribeiro, Nassau County Transportation Department
Mike Schauer, Federal Highway Administration New York Division
William Tibbetts, Alstom Corporation
Paulo Villela, New York State Department of Transportation
Noar Wallach, Alstom Corporation

The Long Island Rail Road, in addition to responding to a large request for data and assisting the authors in their field work, provided extensive comments on the draft final report; their comments have been incorporated into this final report.

Acronyms used in this report:

Acronym	**Full Name**
AADT	annual average daily traffic volume
ATC	automatic train control
BCR	benefit-cost ratio
CBTC	communications-based train control
CWT	constant warning time (before train arrival)
FHWA	Federal Highway Administration, USDOT
FOT	field operational test
FRA	Federal Railroad Administration, USDOT
FTA	Federal Transit Administration
GPS	Global Positioning System
GRS	General Railway Signal Corporation
ICS	intermodal control system (comprised of ATC, IGC, and ITS)
IGC	intelligent grade crossing controller
ITS	intelligent transportation system
LIRR	Long Island Rail Road
NHP	New Hyde Park (Road and LIRR station)
NYSDOT	New York State DOT
O/D	origin-destination
PTC	positive train control
SBP	safe braking profile of train
TOC	Traffic Operations Center
v/c	volume-to-capacity ratio
VMS	variable message sign
VMT	vehicle miles of travel

Executive Summary

The Intermodal Control System (ICS) was designed by General Railway Signal Corporation (GRS, now Alstom, Inc.) for highway-rail at-grade crossings, under contract to the New York State Department of Transportation. In partnership with the Long Island Rail Road (LIRR), a site was selected for testing the ICS at the New Hyde Park station, where a grade crossing occurs close to the station. The planned project integrates train control, grade crossing control, and traffic control into a balanced system that can make decisions affecting both train speed and highway closure.

The purpose of this study is to make quantitative estimates of the benefits that would accrue from deploying technology that would generate the performance characteristics immediately below. While the Alstom system is one comprehensive set of technologies that could produce the characteristics of interest, there are other systems that could produce similar results, and some of the performance characteristics could be produced by smaller or standalone technologies. This report focuses primarily on enumerating and estimating the potential benefits—primarily vehicle delay savings and reduction in collisions—while the specific hardware, software, and vendor sources are given less attention.[1]

At least some of the technology would require systemwide implementation, i.e., on all trains, the entire signal system, and at many crossings. The results and methods described in this report could be used to estimate systemwide benefits of several deployment configurations, but no attempt is made here to extrapolate the benefits to the system as a whole.

Performance Requirements

If the ICS were deployed, the following changes would occur in the operation of the trains and the grade crossing:

(1) **Nearside Stops**. When the train is stopping at the station before the grade crossing (a "nearside" station stop), the gates will remain open and highway traffic will continue to flow; currently the gates remain closed during the time the train is approaching and stopped at the station.

(2) **Constant Warning Time**. Gates will be lowered 30 seconds before the train passes through the crossing, creating a constant warning time (CWT) for

---

[1] See "Technology Components and Information Flows" on page 3 for a brief outline of the Alstom ICS; see Appendix G: "Constant Warning Time Technology" on page 91 and Appendix H: "Vehicle Detection Technology" on page 97 for a review of alternative technologies.

restricting vehicular traffic; currently, gates may be down for variable lengths of time before a train passes.

(3) **Transient Gate Openings**. If a second train coming in either direction would result in the gates being open for less than 12 seconds before lowering again, the gates will remain closed; currently, gates may be raised briefly and then lowered (a "transient" gate opening).

(4) **Stalled Vehicles**. Stalled vehicles or other obstacles in the crossing will be detected automatically, stopping the train if necessary; currently, the existence of obstacles must be detected visually/manually and the information communicated to the train by voice radio.

(5) **Emergency Vehicle Preemption**. Certain emergency vehicles will be able to request that the gates be held open for a given interval, and this request may be denied if the crossing has already passed within the safe braking distance of the train; currently, the LIRR controls the grade crossing signals and gates, and no means exists for emergency vehicle preemption of the grade crossing.

(6) **Variable Message Signs**. Status information will be provided to vehicles and pedestrians via variable message signs (VMS) regarding the reasons for closing and expected time of opening of the gates; currently no information is displayed other than flashing lights.

(7) **Traffic Signal Control**. Timing of vehicle traffic signals will be controlled to minimize the delay caused by gate down time at the grade crossing; currently, signal timing is not affected by whether grade crossing gates are up or down.

These capabilities can potentially benefit train passengers, the train operator, highway users, and pedestrians.

Impacts of the ICS

The performance changes described above can be expected to have several impacts on the transportation system and its users, outlined in simplified form in Figure ES-1. The primary impacts are on vehicle delay and safety.

Train Operations

Railroad trains are traditionally controlled in "blocks" of track, with safety being maintained by not allowing two trains (or a train and a highway vehicle) to occupy the same block at the same time. Depending upon the speed of the train, warning times at a grade crossing may vary widely, encouraging some vehicles to cross the tracks despite flashing lights and lowered gates, creating a risk of vehicle-train collision.

By reducing closing times to a minimum consistent with adequate warning, and making these closing times predictable and reliable to motorists, unnecessary vehicle delay is eliminated and incentives for risky behavior are reduced. Accomplishing this requires having better information about train location and speed than can be obtained from conventional block control.

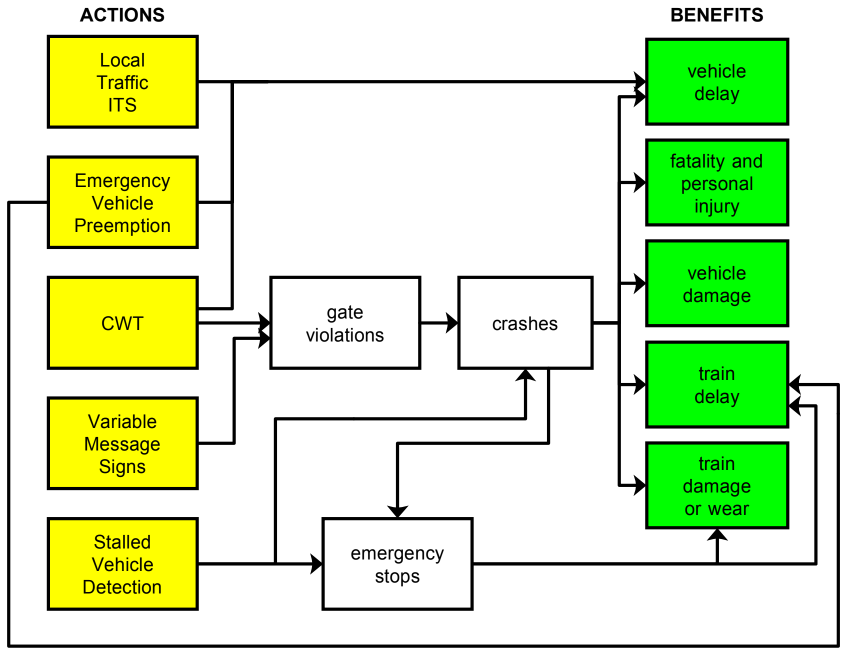

ACTIONS
BENEFITS
Local Traffic ITS
Emergency Vehicle Preemption
CWT
Variable Message Signs
Stalled Vehicle Detection
gate violations
crashes
emergency stops
vehicle delay
fatality and personal injury
vehicle damage
train delay
train damage or wear

Figure ES-1. ICS project actions and related benefits.

Vehicle Traffic

With better train information, closing times are reduced, vehicle queues are shortened, and gate violations are reduced. With knowledge of actual (versus maximum) train speeds, deceleration and acceleration profiles of train consists, and actual distances, the differences in gate closing durations—with and without the ICS—can be estimated, per passing train. Combined with knowledge of highway capacity, highway traffic volumes, and highway geometry, the amount of vehicle delay resulting from a given closing duration can be estimated using deterministic queuing models.

Given the daily distributions of train and vehicle traffic, the results for individual events (single closings) can be extrapolated to annual savings in vehicle delay from deploying the ICS, or some other technology or technologies producing the same performance.

Accident Frequency

Collisions between trains and vehicles, or between trains and pedestrians, occur infrequently (8 accidents at this site in over 25 years), and especially so given the number of trains (approximately 200 per day) and vehicles (approximately 18,000 per day) that traverse the crossing. All the accidents at New Hyde Park Road are "caused" by human error—poor judgment, failure to see a second train, entering the crossing when the exit was blocked by traffic—but this doesn't mean that the likelihood of collision can't be reduced. Given the low probability of an accident for any given train or vehicle, however, the calculation of accident reduction from improved safety treatments at the crossing must rely on statistical models. Such models substitute for the fact that it is effectively impossible to observe the actual impacts of a safety improvement.

Several models have been constructed to estimate expected collisions at a given grade crossing, based on characteristics of the crossing, of which the number of trains and the number of vehicles traversing the crossing are the primary variables. Also of interest, however, are the effects of various treatments, such as warning lights, gates, warning signs, median barriers, and constant warning times. Because the data on which to estimate these impacts are so sparse, and various known statistical problems intervene, the magnitude of treatment "effectiveness" (the extent to which a given treatment reduces the expected accident frequency, independent of other treatments) is as much judgment as rigor.

The Federal Railroad Administration (FRA) has constructed a model that it uses for accident analysis, and this "DOT" model is used for the New Hyde Park analysis. The model contains considerable flexibility in how it is applied, and hence leaves a good deal of room for judgment.

Accident Severity

Common practice in estimating accident costs is to separate frequency from severity, estimating each separately. Hence estimated accident cost is the result of multiplying frequency times severity times the cost of the severity. One collision might result in two injuries and some property damage, each of which has its unit cost. One problem with this strategy is that the type of accident may affect the likely range of severities; a slow-moving freight train is less likely to produce a fatality than a fast passenger train such as on the LIRR. Typically, train-vehicle collision models do not use speed to predict accident frequency, but they do use speed to predict severity.

Most of the trains at New Hyde Park are passenger trains, and the maximum speed for through trains is 80 miles per hour. At maximum speed, a train-vehicle collision is at least 50% likely to produce a fatality, and a train-pedestrian collision is almost certainly fatal. It is no surprise, then, that half the accidents at New Hyde Park have produced fatalities. It is also important, however, to have good data on actual train speeds, including freight trains using the same tracks.

Variable Message Signs

Anxiety and uncertainty for motorists and pedestrians can be reduced by posting messages providing timely information that is useful in the context. Appropriate information helps deter risky behavior such as driving around lowered gates. Hence, variable message signs (VMS) are an important compliment to the ICS. Messages that would be displayed to pedestrians and motorists include those shown in Table ES-1.

Stalled Vehicles

Another possible source of train-vehicle collisions is from vehicles that are stuck on the tracks, either because they are unable to move themselves or because they are caught in a traffic queue. A car that breaks down in the crossing, a truck trailer stuck on a humped crossing, or a traffic backup from a street intersection are examples.

Early detection of stalled vehicles allows the train to slow down and stop before striking the vehicle. There are, however, few data at any level of aggregation that could be used to estimate either the rate at which such stalls occur or the incremental effectiveness of earlier detection.

Table ES-1. Messages to be shown on VMS

Message	Condition
Exit Lane Blocked	vehicle detector records stationary vehicle on opposite side of tracks and informs approaching vehicle so as to deter vehicle from entering the crossing
Train Approach	warning of approaching whether gates are down, or gates are up and train is about to leave the station
Train in Station	displayed while gates are up and train is stopped in station
Another Train Approach	second train coming from the same or opposite direction
Crossing Delay	posted when gates come down and vehicle is occupying the crossing

Emergency Preemption

The ICS provides for a means of holding a train at a slower speed in order to allow an emergency vehicle (police, fire, or ambulance) to use the crossing when it would not be able to do so if the train operated at its normal speed. This is accomplished through a negotiated real-time request, during which it is determined whether a conflict exists, whether the train can be safely slowed, and the length of time that the crossing can be held open to vehicular traffic.

A basic concept here is that the cost of vehicle delay in a real emergency is very high (e.g., arrival at the emergency room seconds earlier may save a life), and may be high enough to outweigh the cost of delay to train passengers and other train costs. The magnitude of benefits depends upon how frequently an emergency vehicle is delayed when slowing the train could avoid the delay.

A complicating, and perhaps offsetting, factor is the difference in the gross benefits of emergency vehicle preemption under base conditions (no CWT) versus under the improved alternative. Because the latter reduces the amount of time the gates are down, the probability of an emergency vehicle being stuck is correspondingly reduced. A satisfactory and perhaps less costly alternative would be to provide real-time train information to the emergency vehicle and let it choose an unoccupied crossing.

Local Traffic Management

Vehicle delay is inevitable when the highway is closed to allow a train to pass, but the amount of delay can be minimized by managing local traffic to maximize flow through the crossing when the gates are open, and minimize the effect of traffic queues on vehicles not seeking to use the crossing. These measures try to increase the road capacity at the crossing and reduce volumes during closures.

The study found that there was little opportunity for application of ITS to traffic management, but substantial potential for improving traffic flow—especially the capacity of the crossing to handle vehicle traffic—from geometric improvements unrelated to the ICS. The most important of these local traffic problems concerns left-turning traffic just south of the crossing (see “Local Traffic Management” on page 36). This traffic conflict creates safety hazards and capacity reduction that could and should be corrected whether or not the ICS is implemented. In such cases, benefit-cost evaluation of the ICS should assume that these corrections are made before implementing the project, i.e., the base case incorporates any readily available non-ICS improvements. This ensures that the ICS project is not being used to correct problems that should be corrected independently. *Thus the base alternative against which ICS benefits are measured has significantly less traffic delay and is substantially safer than that which currently exists.*

Estimated Net Benefits

The ICS can be evaluated as a single package of features, or the features can be evaluated incrementally or in various combinations. While the ICS is a comprehensive integrated system, other strategies and technologies can produce the same or similar results, implemented together or one at a time. Reduced gate violations, for example, sometimes can be achieved with four-quadrant gates or medians, although the latter do not appear feasible in this case. Estimating train arrival time at the crossing more accurately can be accomplished, to varying degrees, by train detection technologies and CWT systems.

Table ES-2. Prototype scenarios for describing conditions

Scenario #	Type of Train	Time of Day	Speed Category	Speed (mph)	Train Passengers	Traffic Volume (veh/hr)	Trains Per Day
1	Through & Far-side Stopping Commuter Trains	Peak	Low	38	2,321	1,110	20
2	Through & Far-side Stopping Commuter Trains	Peak	Medium	63	1,487	1,110	13
3	Through & Far-side Stopping Commuter Trains	Peak	High	74	2,230	1,110	19
4	Through & Far-side Stopping Commuter Trains	Off-Peak		74	2,357	894	94
5	Nearside Stopping Commuter Trains	Peak		40	1,002	1,110	6
6	Nearside Stopping Commuter Trains	Off-Peak		55	645	894	13
7	Frieght/Maintenance/Construction Trains	Night		45	-	102	30
					10,043	6,330	195

Prototype Scenarios

To aggregate the impacts over the range of train traffic, vehicle traffic, and through versus stopping train conditions, a set of prototype scenarios was constructed. Each scenario is taken as representative of the conditions applicable for some portion of the average day. The scenarios are shown in Table ES-2.

Benefits by Action and by Type of Benefit

When a project generates a variety of types of benefit, an obvious question is the extent to which a single category dominates the total, as opposed to the benefits being spread across all categories. The distribution of estimated benefits to the major categories of vehicle delay and reduced collisions is shown in the column totals for the first two columns of Table ES-3. These numbers are output from models that calculate accurately but do not incorporate uncertainty; the results should be viewed as approximate to no more than tens of thousands of dollars with respect to precision.

Table ES-3. Annual benefits by action and type of benefit ($)

Action Type	Vehicle Delay Benefits	Collision Reduction Benefits	Total
Constant Warning Time	$229,074	$193,865	$422,939
Variable Message Signs	-	$80,777	$80,777
Stalled Vehicle Detection	-	$32,311	$32,311
Emergency Vehicle Preemption	$25,936	-	$25,936
Local Traffic ITS	-	-	-
Total	$255,010	$306,953	$561,962

Another reasonable question to ask is whether one *action* generates all the benefits, or whether each of the five or so actions generates an appropriate share of the benefits. This is shown in the row totals in the right-hand column. Constant warning time (CWT) is clearly a primary source of benefit, but other actions are also important.

Incremental Benefits of Separate Actions

Each of the myriad choices for improving safety and reducing delay at grade crossings has its own set of costs and benefits. If there are synergies between features that enhance benefits, or scale economies that reduce costs, the combined deployment will be more attractive; alternatively, piecemeal deployments may be just as effective and require less investment up front. Incremental benefits of implementing portions of the ICS in various combinations are shown in Table ES-4.

Table ES-4. Incremental benefits of partial deployment

Incremental Improvement	Full Deployment	Incremental Implementation
Gates opened for stopped trains	$151,971	-
Stalled vehicle detection	$32,311	$26,926
Emergency vehicle preemption	$25,936	$65,301
Local traffic management	-	-

CWT can be achieved via several technologies, including the automatic train control system incorporated into the ICS, but the method commonly used on some freight railroads may need further modification and testing for application in an electrified system (see Appendix G: “Constant Warning Time Technology” on page 91). Train detection systems that do not rely on track circuitry have been developed and applied, especially in Europe, but standard applications specifically for CWT are not widespread.

Some ICS features can be implemented incrementally or as standalone capabilities. This allows features to be tested and evaluated before deployment systemwide. If, for example, gates could be kept open for nearside stops at stations close to highway crossings, supplemented by VMS information, this feature should be deployed systemwide to maintain consistency, even if the capability is deployed on a standalone basis. Drivers throughout the LIRR service area encounter many crossings, and expect the patterns and policies to be the same at each crossing. Incremental deployment permits the feature to be fully developed and debugged before systemwide deployment.

Costs

Costs for several treatments have been estimated in fairly approximate terms (see “Costs and Benefits” on page 52), and converted to annualized values using a discount rate of 5% and appropriate asset lifetimes. These are shown in Table ES-5.

Table ES-5. Annual Costs

	Annual Cost ($000)		
Actions	with CWT	without CWT	**Components**
CWT (transient gates openings)	46		train detection, position forecasting, communications, processor
Nearside Stop Gates Open	12	18	communications, VMS, processor
VMS	28		install signs, connect to train position information, processor
Stalled Vehicle Detection	18		install detectors, communications, processor
Emergency Vehicle Preemption	23	46	two-way communications, train information processing
Local Traffic Management	23	46	connection to gates, train information, signal controllers, timing plans
Total	150		

Given the modest costs of most of these separate actions, the benefits appear to justify the costs. Full deployment of the ICS could not be evaluated, however, because it would need to be implemented systemwide, not just at one crossing.

Conclusions

Several observations and qualitative conclusions can be drawn based on the data and quantitative evaluation:

(1) If most through trains, especially those during peak periods, pass through the block (approach block plus island circuit) at 80 mph, and the approach circuit is located correctly, CWT is effectively maintained. Under these circumstances, the ICS yields few benefits. Alternatively, if train speeds vary due to track or equipment problems, or for other reasons, ICS benefits are substantial. Both types of conditions have been observed in the field, but data on the overall share of ideal versus compromised conditions have not been collected.

(2) The difference between ideal and compromised operation is highly non-linear, and traffic queues can quickly build to lengths that interfere with local circulation. The New Hyde Park Road crossing sees train and vehicle volumes that are not unduly disruptive to vehicles when the trains move close to 80 mph, but highly disruptive when train speeds vary from 25-60mph.

(3) Benefits from leaving the gates open during nearside stops are already being achieved at some LIRR stations that are located at least 500 feet from a crossing. The technology for accomplishing this is simple and effective. The same solution perhaps could be applied at New Hyde Park with the addition of a VMS that would prevent motorists from being surprised at the nearness of a train (albeit a stopped train).

(4) The danger from gate evasion (vehicle or pedestrian) is primarily the presence of another train, especially because the train could be coming from either direction; this danger could be mitigated by a “second train coming” VMS.

(5) Emergency vehicle preemption of the crossing appears on its face to be relatively low on the list of possible actions that would reduce emergency vehicle travel time; others actions include real-time traveler information about congested locations, and traffic signal preemption by emergency vehicles.

(6) The capacity of New Hyde Park Road appears to be adequate for its current traffic volumes, but is severely reduced at critical times by left-turning vehicles. The worst of these situations occurs less than 50 yards south of the tracks, and often catches vehicles on the tracks because drivers fail to anticipate the sudden blockage. Geometric redesign of this intersection could substantially improve safety and reduce delay.

(7) The full cost of the ICS has not been estimated here because the train control and signal system would need to be implemented systemwide, and no attempt has been made to estimate systemwide benefits (they would include benefits to train operations, such as schedule adherence, not covered here at all). Alternatively, the technologies that could be installed as inexpensive stand-alone systems are either not suitable to electrified environments or have not been developed to the level of reliability required of vital systems in the U.S.

Perhaps the most important lesson to be learned is that evaluation studies of the present sort ought to be undertaken before very much engineering design has been done and before anything is deployed or even field tested. This allows the problem to be defined and its critical parameters identified before a solution is proposed.

Project Description

An intermodal control system (ICS) has been designed for the Long Island Rail Road (LIRR), with the intended purpose of minimizing conflicts between trains and intersecting at-grade highways. A limited field operational test was conducted in June 2001, at New Hyde Park (NHP), NY, a suburban passenger station with a nearby highway crossing. A system map of the LIRR system is shown in Figure 1. The New Hyde Park station is located on the central line at the eastern end of the map (red circle), in Nassau County.

Deployment of the ICS would reduce vehicle delay and train collisions with highway vehicles and pedestrian by establishing five capabilities: constant warning time (CWT), postings on variable message signs (VMS), automatic vehicle detection, emergency vehicle preemption of the crossing, and local traffic management to minimize crossing backups. The purpose of the present report is to estimate whether the value of these benefits exceeds the costs of obtaining them, at a single grade crossing.[2]

Because deployment has not occurred, a benefit-cost evaluation of this system is *prospective*, based on data describing train and highway characteristics and the functionality of the ICS technology, and on simulation and other modeling results. Prospective benefit-cost evaluations should be conducted during the design phase of an upgrade or improvement project, as well as before deployment is implemented, to determine if the benefits can be reasonably expected to occur and to identify which factors they depend upon.

System Performance

The ICS consists of three subsystems:

- Automatic Train Control (ATC),
- An Intelligent Grade Crossing Controller (IGC), and
- An Intelligent Traffic System (ITS).

---

[2] Because the ICS is a CBTC (communications based train control) system, modifications would be required systemwide to the signal system and to the entire train fleet. The LIRR has decided that CBTC will not be implemented in the near future due to the absence of use on other railroads and rail transit systems, and the lack of national standards. In part because of this, the report investigates other technologies that might be able to provide the necessary capabilities through an incremental process. Nonetheless, any deployments should, ideally, be evaluated from a systemwide standpoint, not in isolation.

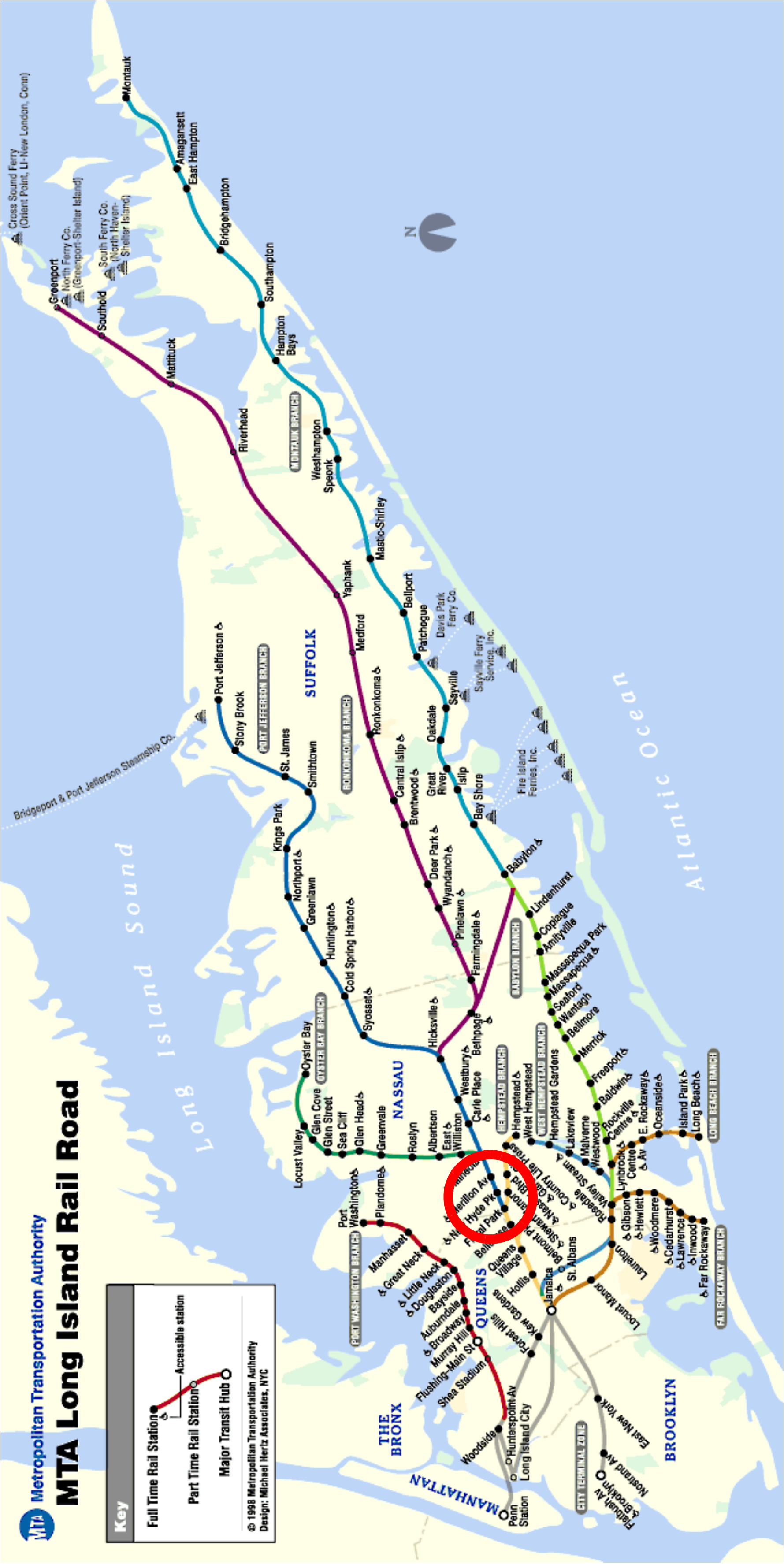

Metropolitan Transportation Authority
MTA Long Island Rail Road
Key
Full Time Rail Station
Accessible station
Part Time Rail Station
Major Transit Hub
© 1998 Metropolitan Transportation Authority
Design: Michael Hertz Associates, NYC
N
Long Island Sound
Atlantic Ocean
MANHATTAN
THE BRONX
QUEENS
BROOKLYN
NASSAU
SUFFOLK
Cross Sound Ferry (Orient Point, LI-New London, Conn)
North Ferry Co. (Greenport-Shelter Island)
South Ferry Co. (North Haven-Shelter Island)
Bridgeport & Port Jefferson Steamship Co.
Davis Park Ferry Co.
Sayville Ferry Service, Inc.
Fire Island Ferries, Inc.
PORT WASHINGTON BRANCH
OYSTER BAY BRANCH
PORT JEFFERSON BRANCH
RONKONKOMA BRANCH
MONTAUK BRANCH
BABYLON BRANCH
HEMPSTEAD BRANCH
WEST HEMPSTEAD BRANCH
LONG BEACH BRANCH
FAR ROCKAWAY BRANCH
CITY TERMINAL ZONE
Penn Station
Woodside
Hunterspoint Av
Long Island City
Shea Stadium
Flushing-Main St
Murray Hill
Broadway
Auburndale
Bayside
Douglaston
Little Neck
Great Neck
Manhasset
Plandome
Port Washington
Forest Hills
Kew Gardens
Hollis
Queens Village
Bellerose
Floral Park
Hyde Pk
Merillon Av
Mineola
New Hyde Park
Stewart Manor
Nassau Blvd
Garden City
Country Life Press
Hempstead
Belmont Park
St. Albans
Jamaica
Locust Manor
Laurelton
Rosedale
Valley Stream
Gibson
Hewlett
Woodmere
Cedarhurst
Lawrence
Inwood
Far Rockaway
Lynbrook
Centre Av
E. Rockaway
Oceanside
Island Park
Long Beach
Westwood
Malverne
Lakeview
Hempstead Gardens
West Hempstead
Rockville Centre
Baldwin
Freeport
Merrick
Bellmore
Wantagh
Seaford
Massapequa
Massapequa Park
Amityville
Copiague
Lindenhurst
Babylon
Bay Shore
Islip
Great River
Oakdale
Sayville
Patchogue
Bellport
Mastic-Shirley
Speonk
Westhampton
Hampton Bays
Southampton
Bridgehampton
East Hampton
Amagansett
Montauk
East New York
Nostrand Av
Flatbush Av
Brooklyn
Carle Place
Westbury
Hicksville
Bethpage
Farmingdale
Pinelawn
Wyandanch
Deer Park
Brentwood
Central Islip
Ronkonkoma
Medford
Yaphank
Riverhead
Mattituck
Southold
Greenport
East Williston
Albertson
Roslyn
Greenvale
Glen Head
Sea Cliff
Glen Street
Glen Cove
Locust Valley
Oyster Bay
Syosset
Cold Spring Harbor
Huntington
Greenlawn
Northport
Kings Park
Smithtown
St. James
Stony Brook
Port Jefferson

Figure 1. Map of LIRR system.

These systems have their own independent functions, and also communicate with each other; together, they enable the operational changes described above ("Performance Requirements" in the Executive Summary on page ix). Features of the ICS include precise information on train location and speed, the ability to provide a CWT, the ability to leave the gates open while the train is in the station, automatic detection of vehicles in the crossing (stopped or not), elimination of transient gate openings, provision of status information to motorists and pedestrians via VMS, the ability to hold the gates open under some circumstances to allow preemption of the crossing by a highway emergency vehicle, and the ability to provide status information to nearby traffic controllers so as to optimize traffic flow during closings and prevent queue buildups across the tracks. Benefits in time savings, accident cost savings, operating costs, and other forms are estimated for each of these features. Benefits accrue to vehicles at or near grade crossings, the operator of the highway, railroad passengers, the train operator, users of emergency services, and pedestrians.

Technology Components and Information Flows

This section presents an overview of the Alstom design for the ICS; for other designs, see Appendix G: "Constant Warning Time Technology" on page 91. Both the technology components and the information flows are represented by the diagram in Figure 2. The three major subsystems are described below.

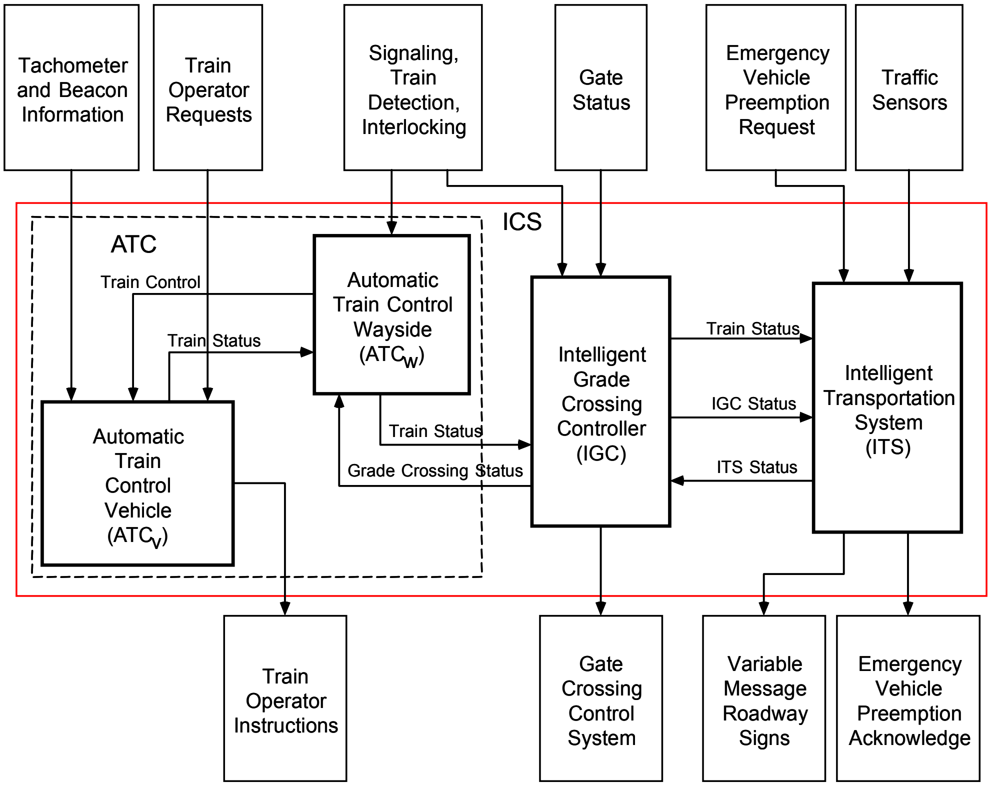
Automatic Train Control (ATC)

Trains on the LIRR are controlled by train operators responding to signals along the track (or in the cab) indicating the presence or absence of a train in the next block(s). A block is a section of track with its own track circuit—an electrical system that detects the presence of a train in the block. The position of the train within the block is not known to the signal system or the grade crossing controllers, and safety procedures require that the "worst case" assumption always be used. If the block is a long section, and crossing gates come down whenever a train enters the block, the actual time of arrival of the train at the crossing could be much longer than the worst case assumption.

ATC replaces the block control system with a combination of transponders ("beacons") mounted on the tracks, readers and tachometers mounted in the trains, and a computer that calculates the position and speed of the train from these data.[3] This information is transmitted to other components of the ICS along with instructions. The ATC maintains a safe braking profile (SBP) such that the train speed is limited by the length of clear track ahead (free of "obstacles"), as well as its predetermined speed and acceleration/deceleration envelope. Whenever an obstacle appears (stalled vehicle) or is placed there (station stop, acceptable emergency vehicle preemption), the train lowers its speed in order to keep the obstacle outside its SBP.

---

[3] ATC is a general term used here to cover PTC (positive train control) and CBTC. PTC is the term most commonly used for ATC-type systems on freight railroads, and CBTC typically applies to rail transit systems.


Tachometer and Beacon Information
Train Operator Requests
Signaling, Train Detection, Interlocking
Gate Status
Emergency Vehicle Preemption Request
Traffic Sensors
ICS
ATC
Train Control
Train Status
Automatic Train Control Wayside (ATC_W)
Automatic Train Control Vehicle (ATC_V)
Train Status
Grade Crossing Status
Intelligent Grade Crossing Controller (IGC)
Train Status
IGC Status
ITS Status
Intelligent Transportation System (ITS)
Train Operator Instructions
Gate Crossing Control System
Variable Message Roadway Signs
Emergency Vehicle Preemption Acknowledge

source: Alstom Signalling, Inc., ELSIE Final Project Report (October 2001).

Figure 2. Components of the Intermodal Control System (ICS)

Intelligent Grade Crossing Controller (IGC)

The function of the IGC is to flash the warning lights on the crossing gate and lower the gate arms before an approaching train. Trains may be through trains (not stopping at NHP) from either direction, inbound trains that pass through the grade crossing before stopping at the station, and outbound trains that stop at the station before proceeding through the crossing. Freight trains also use the same tracks. Currently, this system operates according to signals transmitted by the track circuits when a train is detected. If the train is equipped with ATC, the IGC will overlay the baseline existing control system with the CWT procedures.

Intelligent Traffic System (ITS)

The ITS receives data on the occupancy of vehicle loop detectors deployed at the grade crossing and on nearby streets, and receives requests from emergency vehicles for pre-emption of the crossing. This information is transmitted to the IGC and the ATC. In return, the ITS receives information about whether the request can be accommodated, which it passes on to the emergency vehicles. The ITS also receives information on approaching trains and gate operation, which it displays in the form of messages on the VMS. Finally, information about crossing closures can be used to adjust traffic signal operation in the immediate vicinity.

Table 1 summarizes the performance characteristics of these components.[4]

Table 1. Component Functionality

Component	Performance Characteristics
ITS	select and post up to 20 different VMS messages
	manage up to 20 traffic signal controllers
	receive pre-emption requests from emergency vehicles
	transmit pre-emption permission or denial to vehicles
IGC	override default gate opening/closing instructions (overlay) for ATC-equipped trains
	allow default procedures to function normally (baseline or background) for non-ATC equipped trains
	prevent “transient” gate openings (<12 seconds)
ATC	calculate train position within 3 meters up to 80 mph
	operate compatibly with existing train control system (multimode)
	operate compatibly with existing and planned transit systems

Evaluation Framework

The actions being taken as parts of the project include train control, vehicular traffic control, gate operation, changeable information signs, and real-time information for emergency vehicles. This set of actions can be expected to have impacts on railroad and highway users and providers. The impacts can be classified into three categories: costs, benefits, and transfers. To ensure that the resulting summary of costs and benefits is correct, it is necessary that costs and benefits be measured exhaustively, without overlapping or doublecounting, and that transfers be excluded from the sum.

Costs are typically defined to include initial capital costs only, while operation and maintenance costs, and other valued impacts, are placed in the benefits category, even if they are negative (disbenefits, or cost increases). Transfers are impacts that create gains or losses for individuals or groups but net to zero when considered from the standpoint of society as a whole. Train fares, fuel taxes, and damage liability payments are examples of transfers; they may affect who receives the benefits and who bears the costs, but are not social costs in themselves. Transfers should be included in the analysis of equity or distributional impacts.

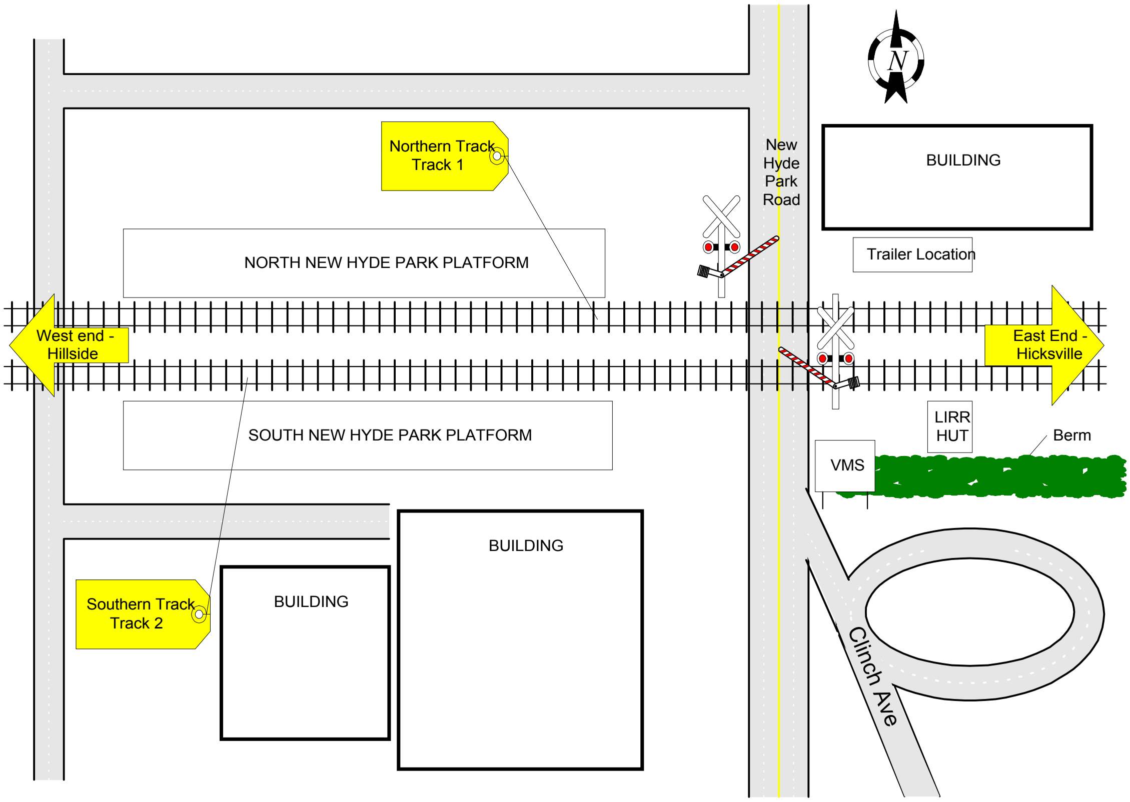
Benefit-cost analysis (BCA) is intended to address the “efficiency” question, namely, are total net benefits received by society as a whole increased by the project or not? A comprehensive BCA can also include an assessment of the “equity” impacts, which includes the distribution of costs, benefits, and transfers among relevant groups within society, such as users versus non-users, highway users versus train passengers, transportation providers versus users, and low income households versus high income households. Equity issues are relevant in the present case because the benefits of intermodal control accrue to the LIRR, highway users, and others, and equitable cost sharing could result in deployment of a socially-beneficial ICS that no single entity would be motivated to pay for.

---

[4] See the Alstom (2001) ELSIE Final Report for a detailed description of the ICS.

Base Case (without the ICS)

Benefit-cost evaluation compares the set of conditions that presently occur and will occur in the future in the absence of the proposed or implemented project, to the set of conditions that occur after the project is implemented. The differences between these two sets of conditions are quantified and valued, and the incremental costs of creating these impacts are subtracted, to yield an estimate of net benefits of the project compared to doing whatever would have taken place in the base case.


N
Northern Track
Track 1
New
Hyde
Park
Road
BUILDING
Trailer Location
NORTH NEW HYDE PARK PLATFORM
West end -
Hillside
East End -
Hicksville
SOUTH NEW HYDE PARK PLATFORM
LIRR
HUT
Berm
VMS
BUILDING
BUILDING
Southern Track
Track 2
Clinch Ave

source: modified from ELSIE Field Demonstration Plan, Alstom Signal Corp, June 2001.

Figure 3. Layout of the New Hyde Park station on the LIRR.

Figure 2 shows the layout of the existing New Hyde Park station and its immediate environs.[5] Current train operation on the LIRR does not provide sufficiently accurate train position information to ensure a constant warning time standard when train speeds vary, does not permit the gates to remain up if a train is in an adjacent block, does not permit preemption by any highway vehicles, and does not automatically detect obstacles in the highway grade crossing. Information about train status is not provided to highway users or pedestrians.

Improvement Alternatives

One or more improved cases can be compared to the base case to assess incremental costs and benefits. To demonstrate the application of the technology, a field demonstration equipped one train with ATC and simulated the instrumentation of one grade crossing with the IGC and ITS. This field test confirmed some operating parameters, for a single crossing, but did not constitute enough of a deployment to provide any evidence of impacts.

The ICS is an integrated system with many capabilities. It can be tested as a single alternative, or the capabilities can be separated and evaluated independently or in different combinations. Because some of the capabilities being evaluated can be obtained via other technologies or partial implementation, an incremental benefit-cost evaluation is included within the scope of the overall BCA. CWT is the most basic capability, and might be implemented with stand-alone train detection methods instead of ATC.[6] Automatic vehicle detection, VMS, emergency vehicle preemption, and local traffic control are in some ways complementary to CWT or depend upon it, but in other ways the benefits of other actions are less once CWT has been implemented, because CWT lowers the baseline vehicle delay and risk levels. These options are presented in the section "Benefits Tabulated by Action" on page 48.

Expected Impacts

The first step is to enumerate as exhaustively as possible all of the potential impacts of the project actions, relative to the base case. The next step is to structure these in an A-causes-B-causes-C series of impact linkages. Subsequently, algorithms and data can be developed that provide a range of quantitative estimates of each of these impacts, including their dollar valuation.

Five distinct actions are encompassed within the ICS, as listed in Table 2. Each action is enabled by some capability implemented in the ICS, such as more precise train location and speed information enabling a constant warning time to be enforced. The action has an impact on the performance of the train-highway transportation system, resulting in several kinds of possible benefits. Different actions may lead to the same kind of benefit (e.g., collision reduction) but via different impact linkages, so the benefits from each action are additive (i.e., they can be summed without redundancy, or doublecounting).

In the next section, the impacts from achieving the performance requirements listed above ("Performance Requirements" on page ix and "System Performance" on page 1) are estimated, working down the list of actions in Table 2. In the final section

---

[5] This diagram is schematic, and not to scale. For more complete information on the crossing and the surrounding area, see Figure 18 on page 38 and Figure 19 on page 39.

[6] Commercial systems in use on U.S. railroads depend upon track circuitry, and cannot be used in an electrified environment. Other systems in use or under development are reviewed in Appendix G: "Constant Warning Time Technology" on page 91.

Table 2. ICS actions, impacts, and benefits

Action	Impacts	Benefits
constant warning time (CWT)	reduce excess gate down time	reduce vehicle delay, reduce vehicle collisions, reduce pedestrian collisions
vehicle detection	stalled vehicles detected before becoming visible to train operator	reduce vehicle collisions, reduce emergency train stops
provision of information via VMS	reduce risky behavior	reduce vehicle collisions, reduce pedestrian collisions
emergency vehicle preemption	allow police, fire, and ambulance vehicles to cross tracks without delay	reduce vehicle delay
local traffic management	facilitate movement of traffic not intending to use the crossing	reduce vehicle delay

(“Synthesis and Conclusions” on page 43), total benefits are aggregated and summarized by type (vehicle delay savings and reduction in collisions), and alternative methods for achieving the benefits are described.

Impacts of ICS Deployment

Impacts are estimated quantitatively for each of the five actions that result from the deployment of the ICS technology. The impacts are traced through linkages to the ultimate benefits, namely, reduced vehicle delay and reduced costs of train collisions with vehicles and pedestrians.

Constant Warning Time

Impacts from Train Position Information

Impact linkages can be broken into several interconnected trees. Figure 4 shows the possible impacts that arise from improved train position information. The benefit of establishing a CWT is both reduced vehicle delay and increased compliance with the crossing gates, resulting in improved safety. Currently, drivers believe from experience that the gates are often down unnecessarily (e.g., the train is sitting in the station) and they sometimes drive around the gates.[7] On occasions, they are struck by a train. The benefit linkages from preventing such risky behavior (expanding from the point in Figure 4 labeled "A") are shown in Figure 5; the two diagrams are actually parts of a single tree structure.

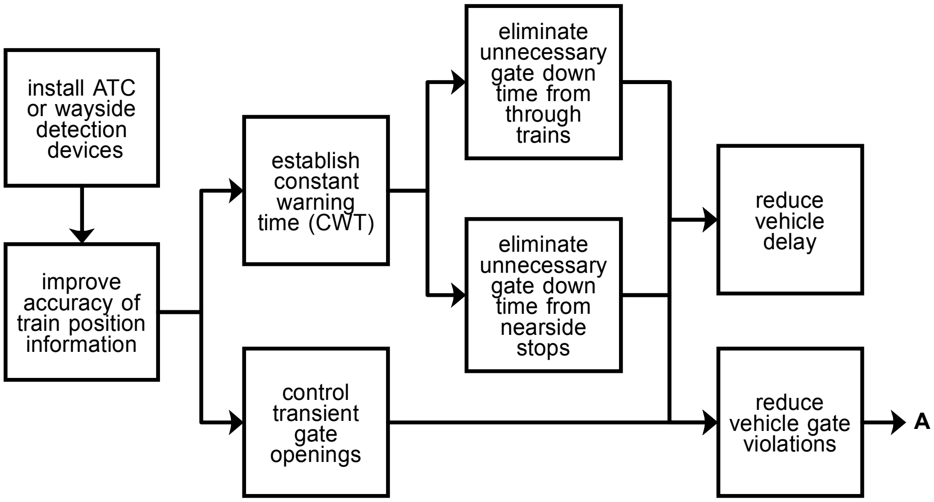

install ATC or wayside detection devices
improve accuracy of train position information
establish constant warning time (CWT)
control transient gate openings
eliminate unnecessary gate down time from through trains
eliminate unnecessary gate down time from nearside stops
reduce vehicle delay
reduce vehicle gate violations
A

Figure 4. Impact linkages from train position information.

---

[7] This behavior has not been observed in on-site visits, and may be infrequent; more common are accelerated dashes under gates that have started descending, and sudden lane changes to avoid stopped queues.

Transient gate openings occur when one train exits the crossing (the gates begin their ascent) and another train enters the approach (bringing the gates down). Openings of brief duration are undesirable because they raise expectations for waiting cars, only to immediately dash them. The proposed standard for the minimum length of time that the gates should remain open is 12 seconds; if the period would be less, the gates are kept closed. This is intended to discourage frustration and hazardous behavior such as trying to slip under the gates while they are closing. Eliminating transient openings will result in fewer collisions, as well as broken gate arms.

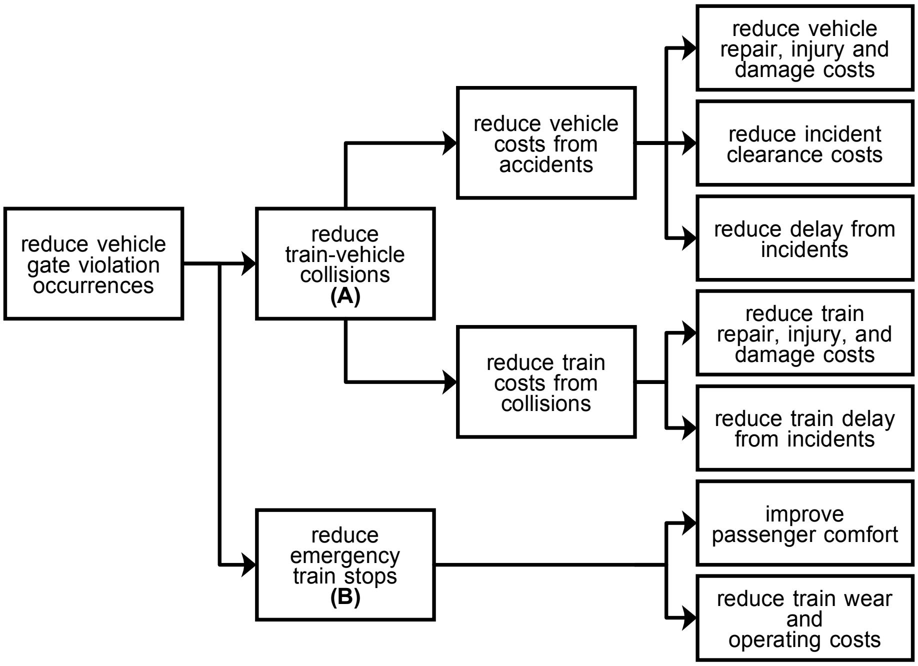

reduce vehicle gate violation occurrences
reduce train-vehicle collisions (A)
reduce emergency train stops (B)
reduce vehicle costs from accidents
reduce train costs from collisions
reduce vehicle repair, injury and damage costs
reduce incident clearance costs
reduce delay from incidents
reduce train repair, injury, and damage costs
reduce train delay from incidents
improve passenger comfort
reduce train wear and operating costs

Figure 5. Impact linkages from increased gate compliance.

Also, emergency train stops might be reduced, other things being equal, by more precise information about the train position relative to possible obstacles requiring a stop. Most collisions, and some near-collisions, are presumed to be preceded by an emergency braking.

Reduce Excess Gate Down Time

With active train control, a constant wait time of 30 seconds before the actual train arrival can be established. Any actual time greater than this is excess down time, creating delay to highway users, and could be eliminated by changing from block control to ATC (or some other system that had accurate train position and speed data). The differences in gate down times between the base (block control) and the improved (constant warning time) alternatives can be estimated for various through-train and stopping train-scenarios.

Automatic Train Control versus Block Control. The traditional and most common form of train control is "block" control, designed on the concept that no more than one train is allowed to occupy the same block at the same time. Trains are detected by means of an electric circuit in the track; the train shunts the current through its wheels and trips a relay. Each block of track is isolated electrically from other blocks.

Where a highway grade crossing occurs with an active control (flashing lights, lowering gate arms), an "island" circuit is placed close to the crossing to indicate when the train has passed and the gates may be opened. A schematic example is shown in Figure 6 (not to scale).

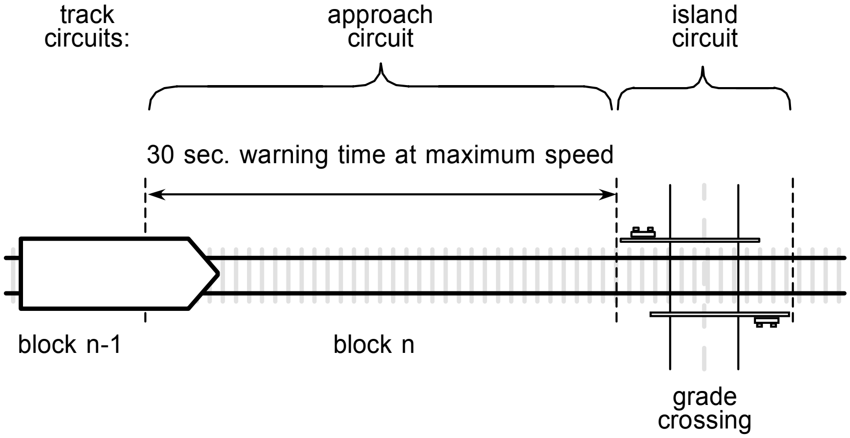


Figure 6. Schematic example of block control for trains.

Because the position of the train within the block is not known, to be safe it must be assumed that the train is traveling at its maximum speed from the moment it entered block *n*. The distance from the island circuit to the track circuit is then set so that the gates can be closed at least 30 seconds before the train arrives.[8] How fast the train is actually moving after entering block *n* is unknown. At NHP, the train may be stopping at the station, slowing for other reasons, or passing through. Hence the gates may be down for times much longer than the minimum 30 seconds. ATC allows both train position and speed to be known more accurately.[9]

Through Trains. The length of the approach circuit (the block before the island circuit) must be long enough to provide the CWT for through trains, and also long enough to stop a through train if the crossing is occupied by a vehicle; whichever distance is longer governs. Typically (Appendix B: "Train Speed Models" on page 59), the CWT determines the length of the approach block. In the present case, the required distance is 3,520 feet to allow a CWT of 30 seconds for a train travelling at 80 mph.[10]

---

[8] The mandatory federal minimum is 20 seconds; times longer than 30 seconds are thought to cause impatience in some share of drivers.

[9] Refer to "Constant Warning Time Technology" on page 91 for more information on automatic train control; see also Hoelscher, Fayos, and Viggiano (1995), and Parsons Brinckerhof Quade & Douglas (1997).

As long as a train is traveling at the maximum permitted speed, there is no excess gate down time. For speeds less than 80 m.p.h., there is some non-zero amount of excess gate down time, as shown in Table 3. Given the number of trains and velocities for these trains, the total amount of time (in seconds) saved with CWT can be estimated.

Table 3. Excess Time Based on Average Velocity

Average Velocity (mph)	Approach Time (sec)	Excess Down Time (sec)
80	37	0
75	40	3
70	42	5
65	46	9
60	50	13
55	54	17
50	59	22
45	66	29

approach distance = 3,520 ft. and CWT = 30 sec.

Trains Stopping at a Station. With block control, the presence of a train within the approach circuit causes the gates to close and remain closed, even if the train is stopped. With additional data on the location and speed of the train within the block, the gates could be left open while a train stopped at a station.

Under the base alternative, the gates are closed once the train enters the block, while it decelerates to a stop, loads and unloads passengers, and accelerates and clears the crossing. The amount of time the gates are down thus depends upon the length of the approach, the speed of the train, the location of the station, the braking envelope of the train, its dwell time in the station, its acceleration profile, and the length of the train. Total gate down time can be decomposed into four component times: the train is moving at constant velocity, the train is decelerating, the train is stopped, and the train is accelerating, as represented in Figure 7 (not to scale). The diagram shows the station near the end of the block, as it is at New Hyde Park; with a different station location, the train might reach cruising speed before it left the block.[11]

Deceleration. For normal in-service braking, the LIRR maintains a constant deceleration rate of about 1.73 miles/hour/second. From equation [11] for time (see Appen-

---

[10] Actual distances at the NHP crossing are 3,585 feet and 3,460 feet.

[11] The LIRR does not allow gates to be left open for stopping trains if the station is closer than 500 feet from the crossing, because it believes that having a train so close can lead to panic in drivers. Providing a VMS message might alleviate the surprise effect. For stations farther than 500 feet from the crossing, the LIRR has means for leaving the gates open and also providing at least 30 seconds warning (with lowered gates) before the train arrives at the crossing after leaving the station.

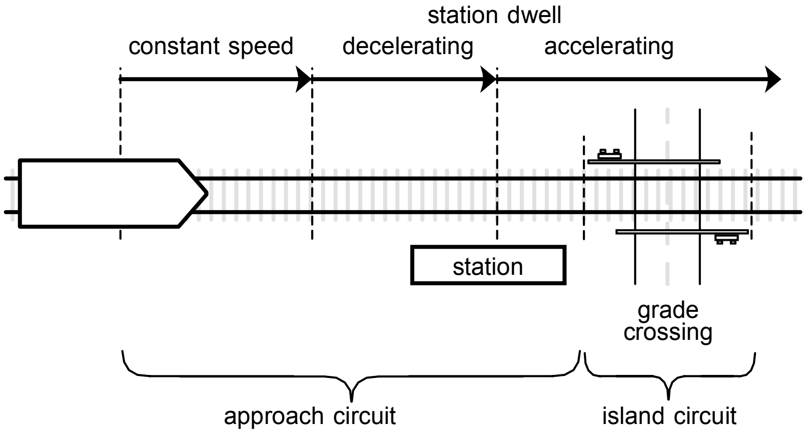


Figure 7. Station placed at end of block

dix B: “Train Speed Models” on page 59) and equation [12] for distance, the distance required is 1,850 feet. This still leaves considerable distance within the block for steady speed operation and, depending upon where the station is, some distance for acceleration.

Dwell Time at the Station. This component of the analysis is the amount of time in which the train is stopped at the station. Actual dwell times vary, and some allowance is made in the train schedule to accommodate larger-than-average passenger boardings and departures. For this analysis, a value of 62 seconds was estimated for dwell time, based on two days of on-site recording of train arrival and departure times.

Acceleration. After the train has completed unloading and loading passengers at the station, it accelerates until it reaches its cruising speed. Assuming the head end of the train is not in or past the highway crossing (a special case considered later), the head will need to reach the far side of the island circuit, then the length of the train must pass.[12]

An acceleration profile for a locomotive type used by the LIRR is shown in Figure 8. The pattern from deceleration is not simply the reverse, in that acceleration at slow speeds is relatively more rapid than at higher speeds. The reasons for the shape of the curve is that as the locomotive approaches its maximum speed, less power is available to push it to go faster.

Gate Down Time per Closing. Adding these four different times together, the total amount of time the gate is down is equal to 133 seconds, which is 96 more seconds than with a constant warning time of 30 seconds. If trains (e.g., freight trains) are

---

[12] Some trains on the LIRR are pulled or pushed by locomotives, and some consist of a mix of self-powered cars and passive cars.

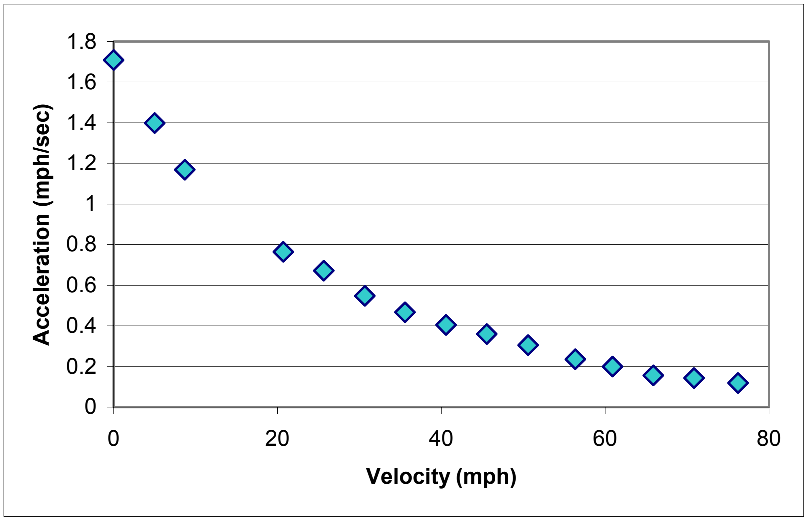


Figure 8. Acceleration as a function of velocity

traveling at less than 80 mph when entering the approach block, the gate down times are also longer than for CWT.

Trains per Year. The LIRR rail network has primarily a tree structure, and the New Hyde Park station is on a main trunk relatively near the root end of the tree. Service is provided 24 hours per day, including weekends and holidays. One branch line stops at NHP, and three other branches pass through, with the number of trains per day on each branch, by direction, for weekday and non-weekday schedules shown in Table 4. Allowance has been made for use of the tracks by freight trains.

Table 4. LIRR trains per day on selected branches.

		Weekdays				Weekends			
		Through		Stopping		Through		Stopping	
Branch	**Direction**	**Peak**	**Off-Peak**	**Peak**	**Off-Peak**	**Peak**	**Off-Peak**	**Peak**	**Off-Peak**
Port Jefferson	eastbound	13	17	7	9	0	21	0	2
	westbound	14	7	7	15	0	22	0	1
Ronkonkoma	eastbound	12	19	2	0	0	3	0	19
	westbound	13	17	3	2	0	4	0	18
Oyster Bay	eastbound	5	9	0	0	0	11	0	0
	westbound	5	9	1	0	0	11	0	0
Montauk	eastbound	1	1	0	0	0	0	0	0
	westbound	1	0	0	0	0	0	0	0
Totals		**64**	**79**	**20**	**26**	**0**	**72**	**0**	**40**
		143		**46**		**72**		**40**	

Basic schedules differ between days of the week and seasons of the year, with additional special trains added in Summer. The number of trains passing through NHP expands to the annual totals shown in Table 20 on page 44.

Reduce Vehicle Delay

Excess gate down time means that the gates could be left open for the passage of vehicular traffic for more time under the improvement alternative than under the base alternative. If the gates were closed for less time, traffic backups would be shorter in both length and duration. Fewer vehicles would need to wait, and those who did would wait for shorter periods.

Vehicle Traffic Queuing. To translate excess gate down time into traffic delay calls for a queuing model of vehicle flow buildup behind a stop, and subsequent dissipation of the queue. The model can be represented diagrammatically as shown in Figure 9. With elapsed time shown on the horizontal axis and cumulative vehicles on the vertical, the slope of line on the diagram represents the rate of flow (e.g., vehicles per hour). The black line through the origin represents the normal flow on the roadway with no gate closing. If a closing occurs starting at 1 minute and continuing until 2.45 minutes, the flow becomes horizontal because time is passing but vehicles are not. When the gate is raised, vehicles commence flowing at the maximum capacity of the roadway, until the queue is dissipated.[13] This is the magenta line labeled “block control.” The area between this line and the uninterrupted flow (vehicles *x* time) is the total vehicle delay caused by the gates being down.

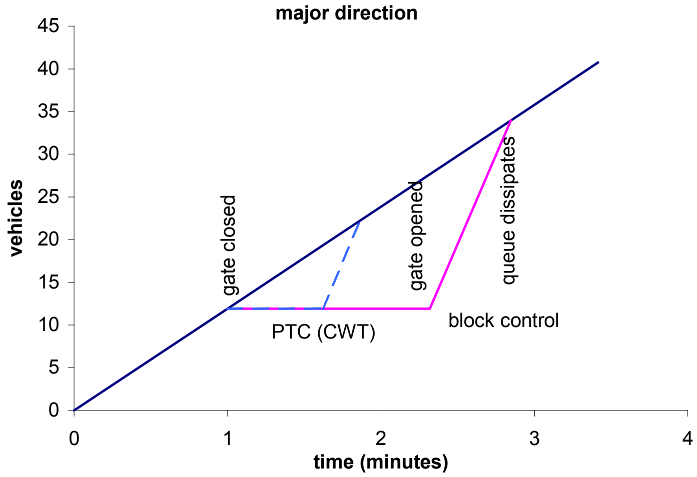


Figure 9. Vehicle traffic queuing model.

Under ATC, the gate down time is less and causes less delay, as represented by the blue dashed line. The difference between these two areas is the vehicle delay that is saved by maintaining a CWT. It is apparent from the diagram that gate down times longer than the average add more to delay than ones shorter than average subtract from it, which means that total delay—for the same number of trains and average down time—is greater to the extent that down times vary about the average.

---

[13] The capacity is actually the “saturation flow rate” defined as “the equivalent hourly rate at which previously queued vehicles can traverse an intersection approach under prevailing conditions, assuming that the green signal is available at all times and no lost times are experienced” (HCM 2000, Exhibit 10-9). The default value for a Class III urban street (free speed of 35 mph) with no turns is 1750 vehicles per lane per hour (HCM 2000, Exhibit 10-7). The “lost times” include startup of the stopped queue, which is ignored here.

A portion of the calculations is shown in Table 5. Directional split is needed to model queues separately in each direction. The distance to the back of the queue may be of interest depending upon the configuration of the highway network. Because the queue has a physical length on the ground, and dissipates from the head, the queue may be getting shorter even though the tail is still advancing upstream. The last vehicle to enter the queue may do so at some distance from the grade crossing.[14]

Table 5. Vehicle queuing delay calculations for stopping trains.

Nearside Stopping Commuter Trains Peak	Block Control			CWT		
	both dir	major dir	minor dir	both dir	major dir	minor dir
Traffic Volume	1,110	588	522			
Road Capacity	4,000	2,000	2,000			
(avg) duration of closure (min)	2.52			0.62		
dissipation time (min)		1.05	0.89		0.26	0.22
max queue at end of closure (veh)		24.76	21.95		6.07	5.38
incident duration (min)		3.58	3.42		0.88	0.84
delay per closing (hours)	1.36	0.74	0.62	0.08	0.04	0.04
daily delay (hrs)	8.43			0.51		
vehicles affected		35.1	29.7		8.6	7.3
max queue length (feet)		618.9	548.8		151.7	134.5
max distance from crossing		876.8	742.5		214.9	182.0

Additional vehicle operating costs associated with gate closings, such as idling, braking and accelerating, have not been estimated here.

Additional Delay From Two-Train Events. A 2-train event is defined for present purposes as the arrival of a train before the (longest) vehicle queue from a previous gate closing has completely dissipated. The impact of two or more trains overlapping in this way is threefold: first, total vehicle delay is greater if closings are bunched rather than spread out; second, the prevention of transient gate openings leads to extending the gate down time; and third, longer-duration closings result in longer vehicle queues that penetrate farther into the local street network, causing delay for vehicles not intending to use the crossing.

Queuing behavior for 2-train events can be studied using a time-flow diagram similar to Figure 9. In Figure 10, the thin (green) line represents a baseline of two closings that occur back-to-back, i.e., the second train arrives just after the queue from the first has dissipated. Because the LIRR uses both tracks to operate trains in both directions, the second train may be going in the same (overtaking) direction or the opposite. In this example, both trains are operating with CWT and the closing is always the CWT plus the time for the train to clear the island circuit, for a total of 0.62 minutes. This

---

[14] See Lawson, Lovell, and Daganzo (1997).

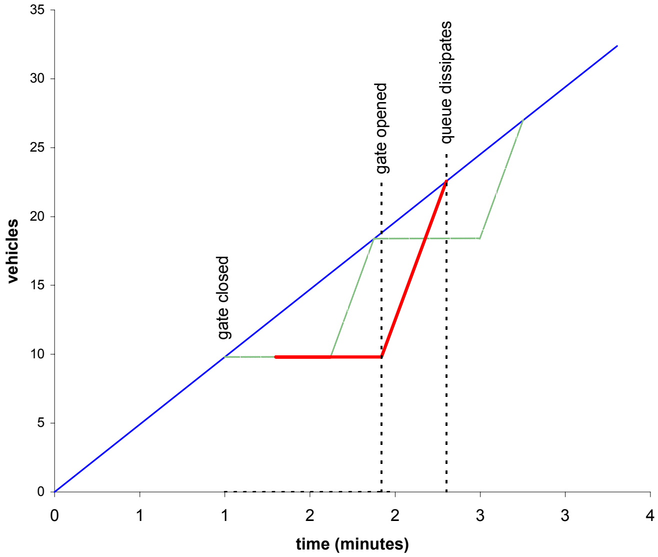


Figure 10. Two-train closing event time-flow diagram.

situation represents the dividing line between single-train and two-train events, and is used simply for reference in the following.

If another train arrives 0.3 minutes after the first, then the closing is extended as shown by the dashed (red) line, and the queue dissipation is pushed back; this extension of the duration of the closing by slightly less than 50% more than doubles total delay time, from 0.08 to 0.18 hours (for both directions; only the major direction is shown in the diagram).

The above analysis assumes CWT for gate closings, and protection against transient gate openings (see "Prevent Transient Gate Openings" on page 23). Average delay (both directions combined) for each of the four possible combinations for these two policies are summarized in Table 6. The base assumes fixed-distance warning time.

Table 6. Average delay per 2-train event, by policy (hours)

	Peak		Offpeak		Night	
	base	CWT	base	CWT	base	CWT
transient gate-openings permitted	0.239	0.103	0.246	0.103	0.021	0.007
transient gate openings not allowed	0.243	0.118	0.260	0.118	0.031	0.017

Frequency of Two-Train Events. Although no data have been acquired that describe the frequency of two- or multi-train events as defined above, an adequate estimate can be constructed via a probabilistic experiment and by assuming randomness (see Appendix C: "Vehicle Queuing Models" on page 67).

Applying this method yields probabilities for the base and CWT alternatives, for three time periods, as shown in Table 7. The greatest likelihood of a 2-train event is during the peak, without CWT; off-peak periods have a lower frequency of trains, and CWT reduces the train's duration (crossing occupancy time plus dissipation), so such conditions generate fewer 2-train events. Converting these numbers to the expected number of 2-train events, multiplying by the number of hours in peak and off peak periods, and summing over the day leads to daily totals with and without CWT. The effect of adding transient gate opening protection to CWT is small (about half an hour of vehicle delay per day). The daily number of trains in each type of period comes from Table 20 on page 44.

Table 7. Expected number of two-train events

	Trains Per Hour	No. Hours Per Day	Closing Duration		Avg No. of 2 Train Events	
			Base	CWT	Base	CWT
Peak	10	6	1.33	0.88	0.5	0.3
Offpeak	9	12	1.35	0.88	0.4	0.3
Night	5	6	1.13	0.64	0.1	0.1

Validation from Field Data. Data on gate down time, traffic volume, queue lengths, and other variables were collected for two days in December 2003. A plot of these data for gate down time versus total queue length (both directions) is shown in Figure 11. Gate down time was measured with a stop watch, but the accuracy of queue length counts diminishes with the length of the queues. Although the data represent peak periods only, traffic flow rates nonetheless varied by a factor of almost

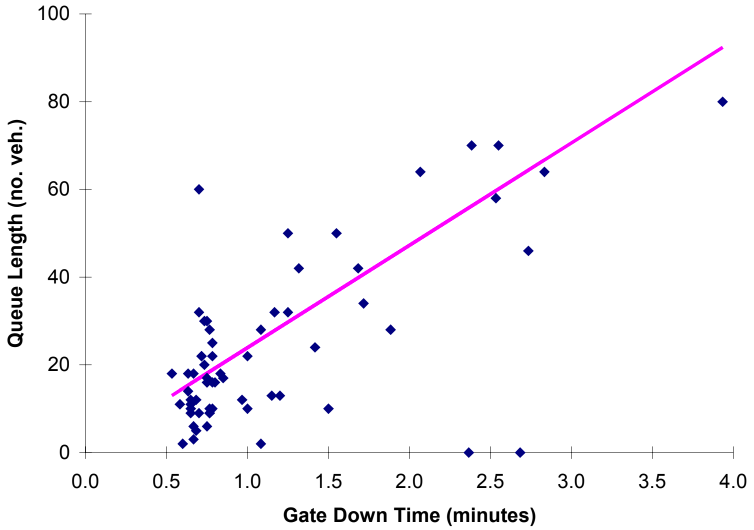


Figure 11. Field data with fitted line for gate down time and queue length.

two, causing widely different backups for the same duration. Despite the brief data collection period and the omission of other relevant variables, a regression line fitted to these data (solid purple line) closely matches the corresponding values from the vehicle queueing model used to estimate delay.

Reduce Train-Vehicle Collisions

Several features of the ICS are hypothesized to reduce collisions between highway vehicles and trains: CWT, which reduces incentives for gate violation; VMS that inform motorists of current conditions, also reducing violations; and automatic vehicle detection, which provides earlier warning of an obstacle to train operators.

Each feature has a distinctive impact, although the first two are mutually reinforcing in reducing risky vehicle behavior. To estimate the benefit of the feature or action, the cost of collisions with and without the feature must be estimated. The cost of collisions can be broken into three multiplicative parts,

$$C_c = Freq \times Conseq \times Cost \tag{1}$$

where C_c = cost of collisions per year, *Freq* = number of collisions per year, *Conseq* = consequences of each collision in terms of fatalities, injuries, and property damage, and *Cost* = dollar cost of each consequence.

An ICS feature that improves safety may do so by reducing the number of collisions, by mitigating the consequences (e.g., lower train speed), and by reducing the unit cost of a consequence (e.g., treating injuries more quickly). Reducing gate violations only affects the first factor, namely, the frequency of collisions. Vehicle detection can potentially avoid collisions as well as reduce train speed at impact. None of the features of the ICS address reducing the unit costs of the consequences.

Accident History. According to Federal Railroad Administration data, eight accidents have occurred at NHP involving trains since 1975.[15] Table 8 contains a complete history of accidents and possible causes at New Hyde Park. Whether the cause of the vehicle accident was gate evasion, traffic queueing, suicide, or other reason is not reported. No data are available on near misses.

Train-vehicle collisions have been declining secularly at the national level, perhaps due to improved safety and perhaps to fewer trains. In 1997 there were 716 collisions at gated public crossings; of these, nearly 20% were the result of the vehicle hitting the train (which was already in the crossing). It is possible that some of these might be deterred by an additional warning in the form of a VMS, but probably not; whatever the cause, such collisions are not for lack of warning (e.g., gates and flashing lights). Of the incidents in which the train hit the vehicle, 35% were “caused” by a gate violation, and another 11% were unknown. Other causes include “not stopping” (i.e., if the vehicle had arrived a few seconds later, it might have hit the train instead of the other way around), “stopped then proceeded” (2%) and “other.” Some share were certainly

---

[15] See the “Web Accident Prediction System” at http://safetydata.fra.dot.gov/officeofsafety/Crossing/default.asp.

Table 8. Accident History at New Hyde Park Since 1975

Date	Fatality	Injury	Vehicle Damage	Train Damage	Narrative
2/15/1979	0	0	$4,500.00	$0.00	Auto drove around gates and was hit by eastbound train
12/5/1980	0	1	$2,000.00	$11,500.00	Auto drove around gates and was hit by eastbound train
7/1/1982	1	0	$50.00	$0.00	Bicycle drove past waiting cars and around gates and was hit by westbound train
11/9/1982	0	0	$800.00	$0.00	Motorcycle stalled on tracks and was hit by westbound train
10/28/1985	0	0	$0.00	$0.00	Auto drove around gates and was hit by westbound train
5/10/1990	1	0	$0.00	$0.00	Pedestrian walked around gates and was struck by westbound train
10/21/1993	1	0	$0.00	$26,900.00	Car was stuck at crossing due to heavy motor vehicle traffic at crossing
8/2/2002	1	0	$0.00	$0.00	Pedestrian walked around gate in Northbound direction – after a eastbound past, walked behind it into the path of a westbound train. 66 year old female killed. No vehicle involved.

caused by vehicles stopped on the crossing (hung up, broken down, waiting at a traffic light, etc.).

Thus the upper bound to which collisions can be avoided by reducing intentional gate violations is about 37% of 81%, or 30%.[16] These statistics pertain to gated public crossings and all trains, of which less than 10% are passenger trains and only a small share of those are commuter trains.

Accident Prediction Models. Ideally, an accident model predicts the expected number of collisions per year at a given crossing based on characteristics of the train traffic, vehicle traffic, and the crossing. To be useful for evaluating crossing treatments, the accident prediction model should include parameters that allow for comparison of expected collisions with and without the feature being evaluated.

Not surprisingly, the models lack parameters that might apply to the ICS.[17] A fundamental and inherent problem with statistical estimation of the impacts of safety devices (gates, flashing lights, etc.) is their endogeneity: such devices are intentionally deployed where collisions are expected to occur, whereas statistical validity would require that the devices be deployed randomly.[18] The fact that device deployment is correlated with the dependent variable (accident frequency) leads to curious results such as gates appear to reduce collisions while flashing lights appear to increase them.[19]

---

[16] Compare this to the roughly 26% estimated effectiveness of CWT, in Table 11 on page 26.

[17] An exception might be the “Other Sign” or “advance warning sign” that is mentioned in Austin and Carson (2001) as a data item available for some states, and used in their estimate of the probability of various safety devices, but the variable does not appear in their accident estimating equation.

DOT Model. A statistical model using data from the FRA grade crossing inventory and accident files was developed in the 1980s for the Federal Railroad Administration by the Volpe Center. Separate models were developed for passive protection, flashing lights only, and gated crossings; however, these separate models do not remove the endogenous relationship outlined in the introduction. The model consists of a set of multiplicative factors in the form[20]

$$a = K \cdot EI \cdot DT \cdot MS \cdot MT \cdot HL \cdot HP \qquad \textbf{[2]}$$

where

Factor	Factor Description	DOT Formula (Flashing Lights and Gates)
K	constant, depending upon type of protection	0.0005745
EI	Exposure index, a function of trains times vehicle	$\left(\frac{Exposure + 0.2}{0.2}\right)^{0.2942}$
DT	Through trains factor	$\left(\frac{ThruTrains + 0.2}{0.2}\right)^{0.1781}$
MS	Maximum timetable speed factor	1
MT	Factor for the number of main tracks	$e^{0.1512 \cdot tracks}$
HL	Factor for the number of highway lanes	$e^{0.142 \cdot (lanes - 1)}$
HP	Highway pavement factor	1
Effect	Effectiveness of protection type relative to base	0.4921

The *Effect* parameter is the only that has been updated; these constants (one for each of the three protection types) are intended to account for secular trends in safety statistics and changes in technology, and are typically referred to as “normalizing coefficients.” The most recent update appears to be for 2002.[21]

---

[18] The endogeneity problem has been identified in the literature (Austin and Carson, 2002). The proposed correction applies the method of Instrumental Variables, which substitutes in the regression a constructed variable, also estimated statistically, which measures the probability that the device is present at each specific crossing. The model is then estimated using these probabilities rather than the actual binary values. For NHP, their model estimated the probability of gates and bells (each) at 0.997. What this means is that there are no crossings similar to NHP that lack gates, so the accident rates at such crossings with gates cannot be compared to similar crossings without gates, using cross-sectional data. Hauer and Persaud (1989) previously described the problem without using the endogeneity label or IV solution.

[19] Several rationalizations have been offered for this anomaly, such as “...flashing lights, due to their active nature, may actually encourage motorists to cross before the train arrives (i.e., beating the train)” (Austin and Carson, 2001).

[20] Mengert (1980); Farr and Hitz (1984), Farr (1987); FRA (2000a, 2000b).

In addition to the basic formulas and the effectiveness factors, the model also has equations for recent accident history (previous 5 years).

$$NA = \frac{(a \cdot T_0) + N}{(T_0 + 5)} \cdot Effect \qquad [3]$$

where

$$T_0 = \frac{1}{a + 0.05} \qquad [4]$$

This adjustment compensates for two influences at the same time. One is the regression-to-the-mean problem, which suggests that a particular observed accident rate may be a temporary deviation above or below the true expected rate.[22] The second is the presence of risk factors at the particular crossing that are not captured in the measured variables (directly or indirectly). Thus the adjustment formula compromises between the estimated rate and the rate implied by Bayesian inference from actual statistics.

When the DOT model is applied to NHP, the estimated rate with updated effectiveness parameters but not local history is 0.217 accidents per year; if the adjustment is made for zero accidents in the past five years, the expected rate drops to 0.063, whereas it only drops to 0.133 with one accident (average of 2 in 10 years). How recent history is interpreted, then, makes a large difference in the estimated accident rate. The values used to describe the NHP crossing to the DOT model are shown in Table 9.

Table 9. DOT accident model inputs for New Hyde Park

through trains (daily)	195
maximum timetable speed (mph)	80
number of main tracks	2
paved (1) or unpaved (2) road	1
number of lanes	4
average daily highway traffic	18,000
accidents in previous 5 years	1
type of grade crossing	Lights and Gates
number of switch trains per day	3
urban (1) or non-urban (0)	1
time-of-day traffic correlation factor	1.20
Technology Factor	1
exposure (trains x vehicles)	4,210,935

The DOT model has some weaknesses, and is somewhat out of date despite some updating of the effect parameter. Several other models have been developed, but none

---

[21] FRA (c.2002).

[22] Bernhardt and Virkler (2002) describe the regression-to-mean phenomenon.

is clearly superior to the DOT model. These models are reviewed and evaluated in "Accident Frequency/Severity Models" on page 79.

Prevent Transient Gate Openings

Openings that would occur for less than about 12 seconds are believed to lead to frustration and attendant risky behavior among vehicles that see the gates go up but are unable to cross before they come down again.

With accurate train location and speed information, the occurrence of transient openings can be predicted and suppressed, holding the gates down if they would be open for less than the required minimum time. The benefits are a reduction in gate violations and related train-vehicle collisions (some minor rear-end collisions among vehicles may also be prevented), with an increase in vehicle delay because the vehicles that could cross during the transient opening are prevented from doing so.

Reduced Collisions. The first impact can be estimated by applying an effectiveness rate to the baseline accident model; as with other effectiveness rates, the value is bounded by rates established for other types of safety improvements, but is based on judgment (see "Effectiveness Rates" on page 24).

Additional Vehicle Delay. With information on the number of trains (by time period), the frequency of 2-train events (from Table 7 on page 18), and the delay under comparable conditions with and without transient gate opening protection, the additional delay from holding the gates down when they would be open for less than twelve seconds can be estimated by setting the threshold to 1 second (to allow for starting the flow from a dead stop) in the base case.[23] The results are shown in Table 10.

Table 10. Additional vehicle delay from transient openings

daily delay without transient gate opening protection (hours)			
	Base	CWT	CWT savings
peak	0.74	0.21	
off-peak	1.33	0.36	
night	0.01	0.00	
	2.08	0.57	1.51
daily delay with transient opening protection (hours)			
peak	0.75	0.24	
off-peak	1.41	0.41	
night	0.02	0.01	
	2.18	0.66	1.52
delay cost of transient gate opening protection (hours per day)			
	-0.10	-0.08	

If transient gate opening protection were added to the base case without CWT (neither likely nor readily feasible), then the cost in additional delay would be about the same as it is under CWT, but the effect is small.

---

[23] Because vehicles typically start traversing the grade crossing as the gates rise but before the flashing lights stop, traffic flow may actually be close to capacity by the time the crossing is nominally open.

Effectiveness Rates

The accident frequency model establishes a baseline from which the impact of a treatment can be extrapolated. Ideally, the frequency model would contain all the factors that might be affected by the treatment, and the model results compared for the "with" and "without" treatment parameters. As mentioned above, none of the frequency models can do this, so the DOT model is used as a baseline against which "effectiveness" of the treatment is a simple (reduction) factor.

Effectiveness is defined (in the grade crossing literature) as the percent reduction in the base rate caused by the treatment, e.g., if the effectiveness of gates over passive warning is 0.82, then the accident rate with gates is 82% less than with only passive warnings. Because it is measured as a reduction from before to after, effectiveness has a positive sign if the rate is lower after the treatment and a negative sign if accident rates go up.

From the observation that a significant share of accidents at gated crossings arise from impatient drivers circumventing the gates has arisen a strong belief among grade crossing analysts that gate violations could be deterred by CWT relative to the base case in which the warning time depends upon tripping the gates at a fixed distance (referred to as FDWT, for fixed-distance warning time). FDWT results in different wait times depending upon the speed of the train.[24] Many studies were carried out in the 1980s to establish the relationship between warning time variability, gate violations, and accidents.[25] Most studies use the national inventory and accident database, but some collected experimental data locally.[26] The studies consistently show a strong relationship between CWT and reduced violations.

The fact that not all gate violations are equally risky has hampered efforts to estimate the relationship between violations and accidents; it becomes necessary to predict the type of violation (e.g., flashing light or police-enforced violation), and to then associate each type with accident rates.[27] The incorporation of the violation rate as an intermediate variable in predicting collisions has not been successful, to the extent it has been tried, so effectiveness factors are used instead, argued heuristically on grounds of reductions in gate violations. Thus, based on available experience and a lack of any explicit models or data by which to measure the impacts of safety treatments, effectiveness rates can be generated for the treatments under consideration:

---

[24] Bowman (1989) outlines a series of impact linkages essentially the same as used in the present study.

[25] See for example Halkias and Heck (1985). They use longitudinal data (before and after an upgrade in protection/warning, which reduces the endogeneity problem) to estimate the effectiveness of CWT versus FDWT, and find that the former reduces collisions by 26% (range of estimate from 3 to 49%) with lights and gates. Aside from numerous data problems in the inventory and accident databases, no attempt was made in the study to control for secular trends. Changes studied include passive to active warning and FDWT to CWT, which also parallel growth in traffic (highway if not train). Halkias and Blanchard confirm that weather and darkness do not explain much about accidents at gated crossings, but they do find that CWT reduces accidents.

[26] Richards and Heathington (1990) collect data on selected crossings in Knoxville, TN.

[27] Carlson and Fitzpatrick (2000) collected supplemental data at 90 sites in Texas via videotape and on-site inspection. When offered an opportunity, drivers chose to cross during flashing lights (FLV) 69% of the time (the rest comply?) and commit an enforceable violation (EV) 34% of the time (the rest comply?). About half of sites had CWT (technology not stated), and the rest had FDWT. Actual wait time is measured and varies due to variations in train speed at the same site. Longer waits result in more EVs, and EVs decrease with train speed (same effect). Their models predict probability of FLV or EV given an opportunity, but "opportunity" is difficult to measure directly; still needed is an opportunity-to-train/vehicle-combination ratio). They cite Abraham, et al. (1997) as having established the relationship between violations and accidents, using the number of violations per train as the independent variable.

(1) **Constant-Warning-Time Safety Benefits**. Several technologies (Appendix G: "Constant Warning Time Technology" on page 91) can be used to estimated train arrival time at a grade crossing. Some of these are labeled CWT (e.g., motion sensors), but do not provide as accurate estimates as others, or do not account for variations in speed after detection.[28] CWT is shown to reduce gate violations, and the effectiveness is independent of other treatments that may be applied.

(2) **Prevention of Transient Gate Openings**. The ICS offers the capability of holding the gates down between sequential trains if the gates would be open for less than some threshold time. The effectiveness of this treatment is unknown, but is estimated in Table 11 on the assumption it reduced gate violations and it is deployed in addition to CWT.

(3) **Variable Message Signs**. VMS reinforce the knowledge that a train will be arriving soon, and provide information that allows drivers and pedestrians to make reasoned decisions rather than guessing (see "Provision of Status Information via VMS" on page 30 and Appendix F: "Variable Message Sign Effectiveness" on page 89). Providing information to highway users and pedestrians is shown to reduce gate violations and risky behavior.

(4) **Stalled Vehicle Detection**. Automatic or remote detection of vehicles stopped in the crossing immediately before arrival of a train should improve safety (see "Detection of Stalled Vehicles" on page 32 and Appendix H: "Vehicle Detection Technology" on page 97). Vehicle detection is believed to reduce collisions, independently of other treatments that reduce collisions or gate violations (these other treatments may, however, reduce the number of vehicles stalled in the crossing).

Estimated values are shown in Table 11.The first column shows the effectiveness if the action is implemented when CWT has also been implemented; the second column shows the effect if only the selected action is implemented.

The weakness of using an effectiveness rate is that it is not tied to any specific parameters, and so can only be adjusted judgmentally. The effectiveness of VMS, for example, is not explicitly dependent upon the rate of gate violation or even the conditions that would create incentives for violation; the rate in Table 11 assumes CWT, which itself reduces incentives for violation, but other factors may also influence driver behavior. The effectiveness of preventing transient gate openings depends upon how often they occur, which is only indirectly considered through the accident model. Use of an effectiveness rate needs to be cognizant of the base from which it is being measured and what is being held constant.

---

[28] See Estes and Rilett (2000).

Table 11. Safety effectiveness values for ICS treatments

Supplemental Safety Treatment	Additional Effectiveness if CWT is already implemented	Effectiveness if implemented separately
Constant warning time (CWT)	-	0.26
Variable message signs (VMS)	0.15	0.00
Prevention of transient openings	0.10	0.00
Stalled vehicle detection	0.06	0.05

Accident Severity

A complete accident model must predict both incidents (collisions) and severity. For highway crashes, there are two scales or sets of categories: the older KABC scale (fatalities, incapacitating injury, evident injury, and possible injury, and property damage only) and the newer AIS (abbreviated injury scale, with 6 levels from fatality to minor, plus PDO). These categories are then matched with theory and empirical data to obtain the average social cost of each category. Expected frequency multiplied by average cost for each category gives the expected costs of accidents (see equation [1] on page 19). Benefits from a safety treatment are the difference in expected cost from lower frequency and lower severity.

Some risk factors affect both frequency and severity. An obvious one for grade crossing accidents is train speed: it is harder to judge the speed of a fast train, and the consequences at impact are greater. The DOT severity model (similar in structure to the DOT frequency model) estimates both frequency and severity, separately, and uses train speed in both models.[29] Comparing the DOT severity model with aggregate accident statistics produces the results in Table 12. The three severity categories are the only ones available from either source. The statistics are for all public gated crossings, all types of trains, while the DOT model is fitted to the NHP crossing parameters.

A tricky problem is the relationship between fatalities and fatal accidents. The statistics report the former, while the DOT model estimates the latter. Shares of accidents by type are needed for partitioning total accidents into categories; the number of fatalities and injuries are needed to estimate the costs of these consequences. The method here tries to use the limited data to best advantage. First, fatality and injury rates are calculated from the statistics (1st column). The corresponding fatal accident rate is estimated using the DOT model for *average* crossing characteristics (presumed to be those generating the statistics in column one), and the ratio of these two (approximately 0.11 from the table and 0.085 from the model, not shown here) gives the estimated fatalities per fatal accident (middle yellow shaded cell). Fatalities per accident (top yellow shaded cell) was taken from the Mironer et al. (2000) study that estimated actual fatalities as a function of maximum train speed. At speeds over 70 mph, the expected rate is an average of 0.5 fatalities per accident. If each (individual) fatal

---

[29] Maximum train speed, however, has no effect in the accident prediction submodel for flashing lights and gates.

Table 12. Severity distributions for accidents and consequences

	Accident Statistics 1997	DOT model (NHP)	estimated accident shares
fatalities	0.11	15%	38%
non-fatal injuries	0.34	22%	18%
property damage only accidents		63%	44%
		100%	100%
fatalities per accident	0.50		
fatalities per fatal accident	1.30		
injuries per injury + fatal accident	0.60		

sources: Railroad Safety Statistics Annual Report 1997 Table 8-2;
US DOT/FRA; Mironer, et al. (2000).

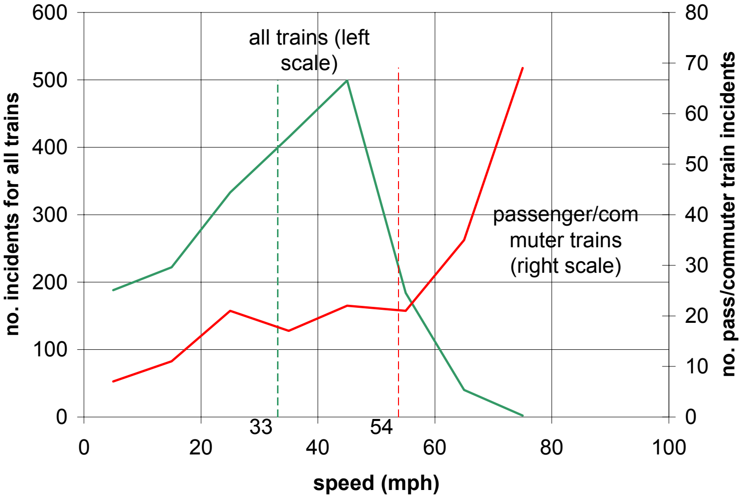
accident generates 1.3 fatalities, then the 0.5 fatalities-per-accident average converts to 0.38 fatal accidents per accident, i.e., 38% of accidents produce all the fatalities. Similarly, injuries are generated by fatal accidents and injury-only accidents at the estimated rate of 0.6 injuries per injury or fatal accident combined (bottom yellow shaded cell). This yields an accident share for injury-only accidents of 18% (implying a rate from fatal accidents of about 0.40 injuries per accident). PDO accidents are the residual. The purpose behind this awkward computation is to account for fatalities per accident and the fact that passenger trains go much faster than average.

Thus the share of fatalities estimated for NHP is higher than the average because of the high proportion of trains at NHP that are commuter trains and the substantially higher speeds of commuter trains relative to the average. Distributions of speed for passenger trains and all trains are shown in Figure 12, along with their weighted averages.

The ratio of fatalities to total collisions or to all injury collisions is especially important at NHP because all reported incidents were fatal accidents. If fatalities are expected to be a small share of accidents, either there are a lot of unreported incidents or the NHP distribution among severities is highly non-random.

Unit Costs of Collisions. A collision by a train with either a vehicle or a pedestrian has several costs, including injuries to vehicle occupants, pedestrians, and train passengers; damage to vehicles, train equipment, and other property; delay to train passengers and vehicles until the accident is cleared and perhaps investigated; and costs for police and other public services.

Train costs per vehicle collision are shown in Table 13. The total train cost per vehicle collision is a weighted average for the costs incurred in derailments as well as non-derailments. Costs consist of damage to the train, injury to passengers, and delay to train passengers. There may be additional costs to the LIRR in the form of alternative transportation (e.g., buses) that must be substituted to maintain service, and ripple effects on train schedules that affect other stops and trains. Derailment costs are large per event, but derailments are rare relative to all collisions. The costs incurred as a



Source: Railroad Safety Statistics Annual Report 1997, Table 8-4.

Figure 12. Speed distributions for passenger and all trains

result of a train derailment were derived from costs estimated in National Transportation Safety Board (NTSB) reports that investigated derailment collisions.[30]

Table 13. Train costs from a vehicle collision

	Type of Collision		Weighted
Cost Category	Derailment	Non-Derailment	Average
damage to train ($)	$3,599,936	$4,500	$4,748
damage to track ($)	$81,541	-	$6
damage to highway vehicles ($)	$2,110,798	-	$146
clearance costs ($)	$17,790	$1,000	$1,001
injury to passengers ($)	$6,610,000	-	$456
average number of trains affected	$97	$20	$20
incident delay per train (hrs)	$6	$0	$0
schedule disruption/alternative transportation	$761,666	-	$53
delay to train passengers	$7,088,532	$80,801	$81,285
total train cost per vehicle collision ($)	$20,270,263	$86,301	$87,694

Vehicle costs per vehicle collision are shown in Table 14. The total vehicle costs for each type of collision include loss of life, injury costs, and vehicle property damage costs. Each type of collision has an expected number of fatalities and injuries as well as an expected amount of property damage. Summing these three components results in the vehicle cost for each type of vehicle collision. Train collision costs not resulting in a derailment were derived by using the Accident Database maintained by the FRA's Office of Safety Analysis.[31]

---

[30] The reports are http://www.ntsb.gov/Publictn/1998/RAR9801.pdf, http://www.ntsb.gov/Publictn/1998/RAR9802.pdf, http://www.ntsb.gov/Publictn/2001/HAR0102.pdf, http://www.ntsb.gov/Publictn/2001/HAR0103.pdf, and http://www.ntsb.gov/publictn/2002/HAR0202.pdf.

Table 14. Vehicle costs from a vehicle collision

	Type of Collision		
Cost Category	Fatality	Injury	PDO
average number of fatalities	1.30	-	-
average number of injuries	0.60	1.1	-
total vehicle costs per vehicle collision ($)	$3,964,680	$114,680	$4,680

For a pedestrian collision, there are still train costs incurred by the train operator as well as costs to the pedestrian. The costs to the train are small, whereas the pedestrian costs are significant since the vast majority of pedestrian accidents result in a fatality. Train costs in a pedestrian collision were estimated by using the train costs previously reported by the LIRR for pedestrian collisions in the FRA database. Since all the pedestrian collisions at the NHP crossing have resulted in the death of the pedestrian, $3,000,000 was used as the cost to the pedestrian. This number is the current cost of a fatality. The total costs for a pedestrian collision is shown in Table 15.

Table 15. Total costs from a pedestrian collision

Cost Category	Cost
train costs	$250
pedestrian costs	$3,000,000
total cost per pedestrian collision	$3,000,250

The final step in determining the unit cost of a collision is to average the collision cost for pedestrian and vehicular collisions according to their associated probability of occurrence. For New Hyde Park, the annual cost of collisions can be determined using the expected number of collisions and the collision cost for each type of collision (pedestrian and vehicular). The estimated expected cost of an "average" collision at NHP is shown in Table 16.

Table 16. Total cost of a collision

	pedestrian	vehicular
collision cost ($)	$3,000,250	$1,635,107
collisions per year at NHP	0.1071	0.1327
total cost of a collision ($)		$538,513

---

[31] http://safetydata.fra.dot.gov/officeofsafety/Downloads/Default.asp.

Provision of Status Information via VMS

An array of messages can be displayed at the grade crossing by means of variable message signs (VMS) that are posted in real time. The messages provide information to guide vehicle or pedestrian behavior, or to offer reassurances that enhance the credibility of the traffic control system.

Change Driver Behavior

The main purpose of the messages is to inform highway users what to expect and to reduce their frustration at having the gate blocking their route. One effect, shown in Figure 13, is to discourage non-compliance with the gate and signal indications, leading to reduced collisions as in Figure 5. For example, on nearside stops the gates could remain open, allowing traffic to pass, while a VMS alerted motorists to the presence of a stopping train or stopped train in the station. In addition, even if motorists would not be inclined to evade the gates, the reassurance that delays will not be lengthy and that things are under control is a benefit in reduced disutility of waiting time. Drivers may also be less likely to seek alternative routes.

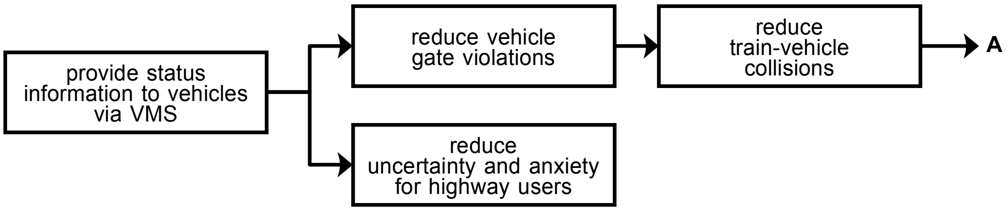

provide status information to vehicles via VMS
reduce vehicle gate violations
reduce train-vehicle collisions
A
reduce uncertainty and anxiety for highway users

Figure 13. Display of train status on VMS.

Studies of the effectiveness of VMS at changing driver behavior seem to be sparse. Combined with CWT, the VMS should strengthen the deterrences to circumvent lowered gates, and also increase awareness of the crossing.

Change Pedestrian Behavior

Pedestrians are also affected by the VMS and the altered operation of the gates. VMS provide useful information to pedestrians as well as vehicles, and should discourage pedestrians from crossing the tracks when that is risky, especially when there is a second train coming. Having the gates open to highway traffic for a longer time does leave pedestrians with less opportunity to cross the street when traffic is stopped. In particular, train passengers leaving the station before the train pulls out (of a nearside stop) may not be able to cross the street as easily. Overall, however, the improved predictability of the closings, reinforced by the message signs, should benefit pedestrians as well as highway users. The pedestrian effects are shown in Figure 14.

A project applying signing at a pedestrian crossing with a light rail line in Los Angeles produced some interesting results.[32] Trains travel at speeds up to 55 mph. The treated crossing is adjacent to a station, regarded as a major pedestrian risk location

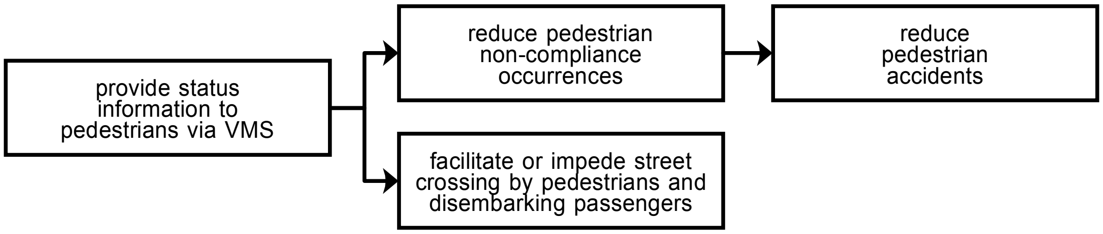

provide status information to pedestrians via VMS
reduce pedestrian non-compliance occurrences
reduce pedestrian accidents
facilitate or impede street crossing by pedestrians and disembarking passengers

Figure 14. Pedestrian benefits from VMS

(17 accidents in 10 years, with 5 fatalities including 1 suicide). In this case, a second train in the opposite direction was a major factor. The VMS is 3'x4' along with flashing lights and bell. Data were collected on 1,470 2-train events (including freight), averaging 25 per day. Pedestrian behavior was monitored via video cameras. The sign had the effect of reducing risky crossings (6 and 10 seconds before train) by about 30-50%. Some risky behavior went up, perhaps suggesting (besides randomness) that the additional information allowed more crossings to take place at the same risk level.

By reworking the data published in the report, it was possible to calculate the response rate as a function of the time before the second train arrived. The deterrence rate for the shortest time (4 seconds) is dramatically higher than for longer times; most of the people who walked out immediately in front of a train chose not to do so when informed of the fact, implying that they weren't aware that the train was so close.

Table 17. Risky pedestrian crossings

Time Before Train	Before	After	% Change
6<15 seconds	321	286	-11%
4<6 seconds	44	36	-18%
<4 seconds	15	4	-73%
<6 seconds rate	4.0	2.7	-33%

rate is per 100 two-train events (n=1,470)

Other kinds of pedestrian signalization and channelization can also be effective.[33] While it seems very intuitive that a reduction in pedestrian risky behavior should lead to a reduction in pedestrian accidents, the relationship is still largely undocumented in present research. In the LA study, the accident rate actually increased from 1.4 (14 accidents in 10 years) to 2.4 accidents per year (3 accidents in 1.23 years) while risky pedestrian behaviors decreased. This result might be explained by the small after-treatment sample size.

---

[32] PB Farradyne (2002)

[33] See, for example, Lalani, et al. (2001).

Potential risks exist with any safety treatment, including VMS. One is that motorists and pedestrians may become dependent on a non-vital system and fail to take precautions they otherwise would. Similarly, motorists and pedestrians may compensate for the increased safety by engaging in more risky behavior, such as crossing in front of approaching trains. Economists refer to this response as “moral hazard.”

Looking at the number of pedestrian accidents at New Hyde Park in the past 28 years, there have been 3 reported pedestrian accidents, all resulting in fatalities. This averages to approximately 0.1 accidents per year. Using the cost of a pedestrian accident from Table 15 on page 29, this results in an annual cost of about $321K. Applying the effectiveness rate from Table 11 on page 26 of 15% implies a savings of around $48K per year. Based on Table 17, the effectiveness rate of VMS for pedestrians is at least twice that shown in Table 11, at least as measured in deterring risky behavior.

Detection of Stalled Vehicles

Automatic detection of vehicles in the crossing—whether stalled, or stuck in the crossing due to backed-up traffic or other causes—gives the train earlier information about the obstacle. This should reduce train-vehicle collisions, as represented in Figure 15.

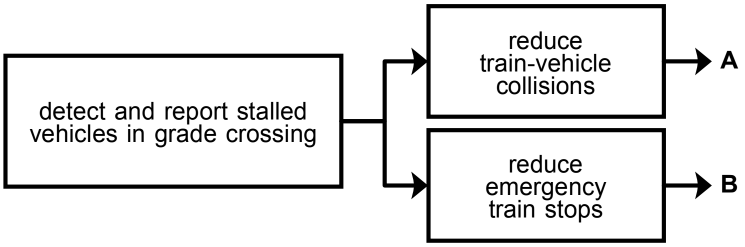

detect and report stalled vehicles in grade crossing
reduce train-vehicle collisions
reduce emergency train stops
A
B

Figure 15. Impacts of stalled vehicle detection.

Reduce Collisions

The benefits of fewer collisions represented by “A” were detailed previously in Figure 5 on page 10 (starting at the letter *A*). Similarly, the benefits of reduced emergency train stops are continued in Figure 5 starting at letter *B*. Automatic vehicle detection and warning, however, creates the possibility for false positives (a vehicle or obstacle is indicated when no vehicle is present), which may lead to some number of unnecessary stops or slowdowns that would not have occurred without the detection capability. The likelihood of such errors can be minimized by providing redundant or overlapping detection systems, such as video cameras plus imbedded detectors. With an ATC, communication with the train would be through the ICS; without ATC, communication to the train would be via radio signal.[34]

---

[34] See Figure 2 on page 4 and Appendix H: “Vehicle Detection Technology” on page 97.

For the purpose of estimating the reduction in collisions due to detection of stalled vehicles, there is not much more that can be done other than apply an effectiveness rate from Table 11.

Reduce Emergency Stops

Emergency stops occur before collisions and before near-collisions, once the train operator has seen an obstacle on the tracks that is in danger of not clearing the tracks in time. When a train makes an emergency stop, the wheels are locked and the train slides along the track, damaging the wheels and the track. The train is also delayed. The estimated cost of an emergency stop in delay and train damage is shown in Table 18. These numbers are no more than plausible guesses.

Table 18. Cost of emergency stops

Cost Category	Value
repairs to train	$5,000
average time delayed	10
passenger delay cost	$2,020
emergency stop %	50%
average number of emergency stops/yr	0.1991
cost of an emergency stop	$7,020
annual emergency stop cost	$1,398

It is assumed, in the absence of data, that the baseline for the number of emergency stops per year is the number of reported collisions plus some additional factor, taken here as 50%, yielding a rate of 0.1991 stops per year.

Emergency Vehicle Preemption of the Grade Crossing

Emergency vehicles may request that the grade crossing be held open for some specified duration, and the train may grant permission if it is safe to do so with respect to the train's safe braking curve. This communication allows for a high-priority vehicle to save time at the expense of some train time. At present, there is no way to make this tradeoff. Positive benefits occur when the value of the savings to the emergency vehicle exceed the costs to the train operator and train passengers. The impact linkages are shown in Figure 16.

Preemption Procedures

The preemption process can be broken into four steps, each step having functional requirements that can be met in several ways:

(1) An emergency vehicle (EV) requests preemption. Communication between vehicles and traffic signals is typically via optical (strobe light), acoustic (siren), special loop detectors (that recognize the vehicles), or GPS.

(2) The request is validated and authorized (or denied).

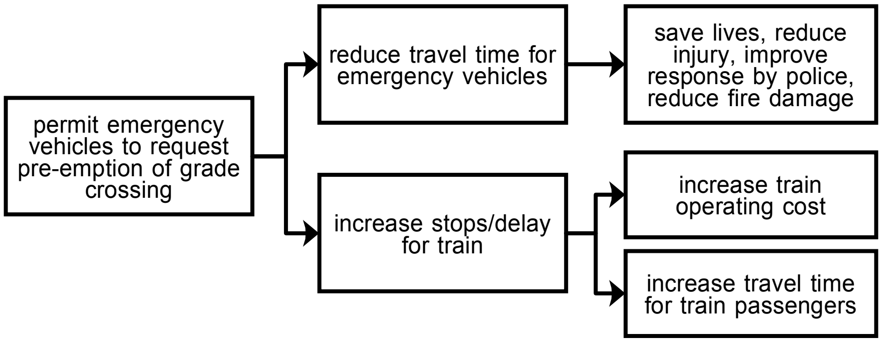

permit emergency vehicles to request pre-emption of grade crossing
reduce travel time for emergency vehicles
save lives, reduce injury, improve response by police, reduce fire damage
increase stops/delay for train
increase train operating cost
increase travel time for train passengers

Figure 16. Grade crossing preemption by highway vehicle.

(3) The approaching train responds by decelerating in order to keep the grade crossing warning device from triggering.

(4) The preemption is terminated and the grade crossing controller (and any traffic control devices) transitions back to normal operation.

Communication between EVs and the railroad requires a radio format not dependent upon close proximity or line-of-sight. Authorization for the railroad is more complicated than for highway signal preemption.[35] In contrast to traffic signal response, however, railroad gate options are simply to remain open or to close. The recovery phase is similar to traffic preemption, in that schedules for subsequent trains may be disrupted by slowing a particular train.

The ICS emergency vehicle preemption would follow a specific protocol: 2 minutes before reaching the crossing, the emergency vehicle would request permission from the railroad to hold the gate open; if the railroad determined that this would be acceptable, the gate would remain open for 30 seconds. The EV could then make up to three subsequent requests, until (1) the two minutes was up, (2) a request was denied, or (3) the vehicle was through the crossing.[36]

An operating policy acceptable to the railroad might consist of (1) if no train was near enough to the crossing to cause conflict, the gate could stay open; (2) if a train was too close to the crossing to safely hold the gates open, the request would be denied; (3) if one or more trains could be safely slowed and the crossing gates held open to allow for the EV, the gates would be held open; or (4) if the delay imposed on the trains would cause impacts on overall train schedules that would warrant refusing the EV request, the request would be denied. A simple rule of thumb might be to deny any request that would delay another train besides the one nearest the crossing.[37]

---

[35] A traffic signal preemption request may be denied automatically, based on preset rules (e.g., too many requests within a short time span)

[36] Details for one method are provided in Alstom Signalling (2001).

If emergency vehicles preempt traffic signals infrequently in a highway system, even one that is fairly close to capacity, the disruption can be minimized with appropriate response and transition algorithms.[38] For trains, the problem is less complex (the network is much simpler) but there is less flexibility in adapting to or recovering from imposed delays.

Delay Savings for Emergency Vehicles

If the EV request is refused, the vehicle has the option of waiting for the crossing to reopen or detouring to an open crossing. The real-time negotiation described above would require accurate information on train locations, speeds, and travel times over alternative highway routes for the emergency vehicle. Such information could improve travel times for emergency vehicles even without preemption of the crossing.

Some share of emergency vehicles that need to cross the LIRR tracks at New Hyde Park Road are delayed, detour to another crossing, or divert to another destination, e.g., an alternative hospital. With the implementation of the ICS, this delay and diversion will be reduced even without pre-emption of the grade crossing. Thus EV preemption can be compared to a (1) base case that represents existing conditions without CWT, or (2) a base in which CWT has already been implemented.[39]

Delay savings to EVs can be estimated using

$$EV_{\text{delay savings}} = N \times P_c \times S_P \times D \qquad \textbf{[5]}$$

where N = number of EVs using the crossing per year, P_c = probability the crossing is closed, S_p = share of EVs successfully gaining preemption, and D = average delay avoided per preemption. The probability the crossing is closed is

$$P_c = \frac{\text{average gate down time in hours per train} \times \text{trains per year}}{\text{hours per year}} \qquad \textbf{[6]}$$

These factors are shown in Table 19 for fixed distance (base alternative) conditions and for CWT. Data for estimating the number of EVs using the crossing, and the share justifying preemption and doing so successfully are described in Appendix I: “Preemption by Emergency Vehicles” on page 101. Average trip delay is half the average gate down time, on the assumption that emergency vehicles can jump the queue whether the gates are down or up (but not go through lowered gates). The value of emergency vehicle time is derived from a value of life of $3 million and evidence

---

[37] Further discussion of this rule of thumb can be found in Appendix I: “Preemption by Emergency Vehicles” on page 101.

[38] Nelson and Bullock (1999) test (through simulation) the effects of preemption on coordinated traffic signals, under three transition algorithms (called smooth, add only, and dwell), and conclude that the additional time for non-favored traffic need not be large (e.g., above 30 seconds per vehicle) with suitable adaptations.

[39] The benefits to EVs from CWT (without any emergency preemption) is assumed to be captured in the average value of time for delay savings from CWT, even if the EVs actually avoid closed crossings.

Table 19. Emergency Vehicle Preemption Benefits

	base case	CWT
number of emergency vehicle trips (per year)	2,250	
percent of trips crossing railroad tracks	31%	
number of trains (per year)	71,157	
gate down time (second per train)	58	37
annual gate down time (hours per year)	1,155	734
share of time gate is down (percent)	13%	8%
number of emergency trips delayed (trips per year)	92	58
share of trips warranting preemption (percent)	20%	
annual number of trips requesting preemption	18	12
successful preemption requests (percent)	50%	
annual trips successfully gaining preemption	9	6
average emergency vehicle delay per trip (minutes)	0.49	0.31
annual delay savings from preemption (minutes)	4.5	1.8
increased survival rate per minute reduced arrival at hospital	0.5%	
value of life ($)	$3,000,000	
value of emergency vehicle time ($/hour)	$900,000	
value of travel time savings to emergency vehicles	$67,159	$27,116
average delay to train (minutes per preemption)	1.00	1.00
average passengers per train	488	
value of delay time to train passengers	$1,858	$1,180
Annual Benefits of Vehicle Preemption of Grade Crossing	$65,301	$25,936

that for each second that is saved in a severe trauma case there is a 0.5% increase in chance of survival (refer to Appendix D: "Valuation of Travel Time" on page 71).

Costs to Train Passengers

Passengers aboard trains may experience some delay due to preemption. The amount of time a train is delayed per preemption (estimated to be 1 minute per occurrence) is equal to the time it takes the emergency vehicle to cross the railroad tracks plus the time that the train needs to return to its previous speed. This delay is multiplied by the average number of passengers per train and the cost of their time, which yields a cost to train passengers for each alternative.

If gate down times are substantially reduced, the benefits of preemption are correspondingly reduced (there is less potential for conflict). Enabling either preemption or path optimization (real-time rerouting) with the present train control system, however, would be both difficult and also less effective, because knowledge of train position in real time is not very accurate. If train position information is improved (via ATC, GPS, or wayside detection), then gate down time could be reduced, emergency vehicle preemption could be made more precise, and emergency vehicles could be provided with information allowing them to avoid closed crossings at the least time cost. Improved train position information seems to be a prerequisite for any of these.

Local Traffic Management

With real-time information about gate closings before and during train arrivals, traffic signal timing can be adjusted to minimize the disruption from the blockage and take advantage of paths that are not blocked. Queues which will occur anyway due to the closure can be stored in the most convenient locations. The benefits of managing traffic opportunistically or adaptively depend upon the capabilities of the signal controllers, the presence and locations of vehicle detectors (such as inductive loops), and the extent to which the signals are tied together (such as through a traffic operations center). The linkages of the potential benefits are indicated in Figure 17.

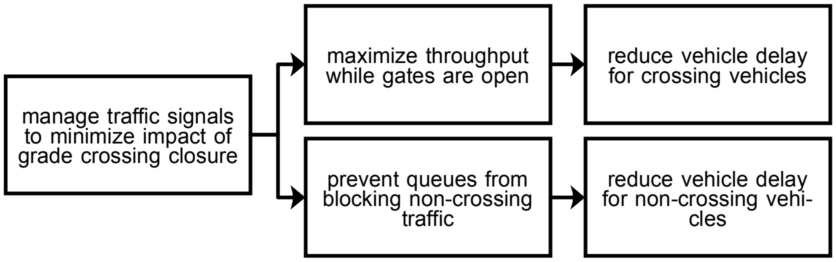

manage traffic signals to minimize impact of grade crossing closure
maximize throughput while gates are open
reduce vehicle delay for crossing vehicles
prevent queues from blocking non-crossing traffic
reduce vehicle delay for non-crossing vehicles

Figure 17. Impacts of traffic management at nearby intersections.

A street map of the portion of New Hyde Park surrounding the station is shown in Figure 18. The nearest signalized intersections are on Jericho Turnpike, and none are within the range of 200 feet that would require an interconnect, or grade crossing preemption that would clear any intersection legs that might queue over the tracks. There are, however, some traffic situations that can generate backups onto the crossing. If these warrant traffic control devices and interconnects to ensure that hazardous situations do not develop, the improvements should be considered to be part of the base case for evaluation of the ICS.[40]

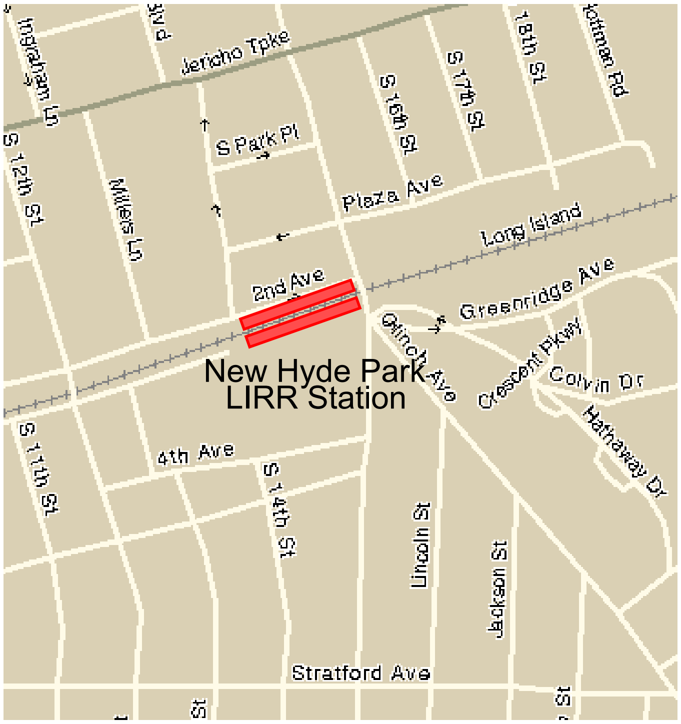
Because of the absence of traffic signals or other traffic control devices that might be used to implement ITS strategies, no benefits are estimated for the local traffic management category. An example of the analytic methods that might be useful if such actions were feasible is provided in Appendix J: “Facilitating Local Traffic With ITS” on page 105. The remainder of this section describes some of the traffic problems that are assumed to be corrected in the base case.

Local Traffic Problems

There are several problem spots that are specific to streets near the New Hyde Park Road grade crossing. These problems affect both delay from closings and safety at or near the crossing. Because the associated delay could be reduced by correcting the local traffic problems, without implementing any of the ITS components, these corrections *are included in the base case*. This means that much of the observed delay at the crossing is assumed to be already eliminated, for purposes of evaluating the ICS improvements.

---

[40] The distance for mandatory preemption is set by the MUTCD. Because of the 1995 accident at Fox River Grove, Illinois, in which a school bus waiting at a traffic light was hit by a train and seven children killed (NTSB, October 1996), a large amount of attention has been directed at interconnect timing and the factors of variability (Korve, 1999; Venglar et al., 2000; ITE, 1997). Additional treatments include advance preemption time (a sensor activated in advance of the approach circuit) and pre-signals (traffic signals that prevent vehicles from entering the crossing when there is a red traffic light on the other side)

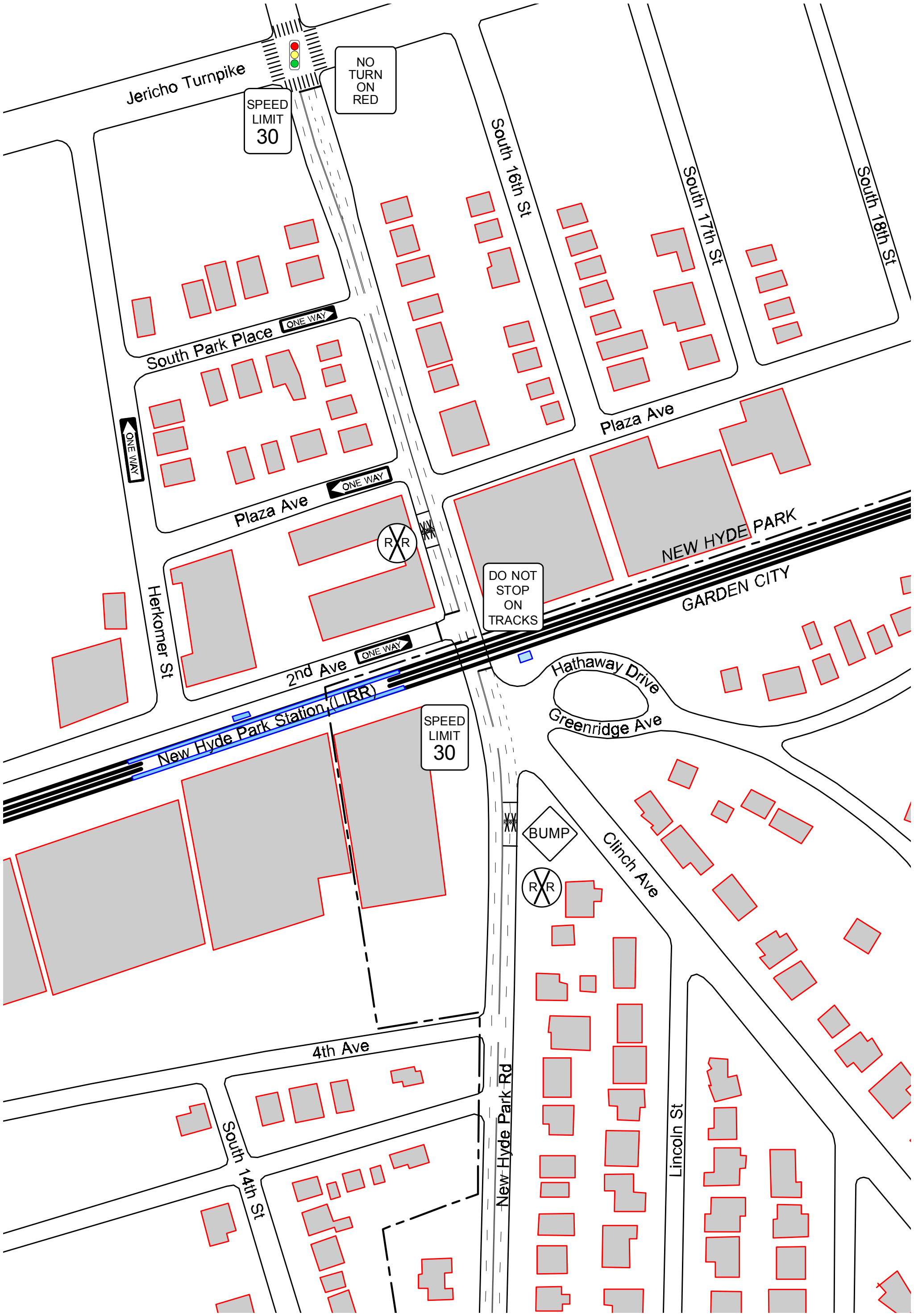

Ingraham Ln
Blvd
Jericho Tpke
S 16th St
S 17th St
18th St
Hoffman Rd
S 12th St
S Park Pl
Millers Ln
Plaza Ave
Long Island
2nd Ave
Greenridge Ave
New Hyde Park
LIRR Station
Clinch Ave
Crescent Pkwy
Colvin Dr
Hathaway Dr
S 11th St
4th Ave
S 14th St
Lincoln St
Jackson St
Stratford Ave

source: MapQuest base map.

Figure 18. Streets in the neighborhood of the New Hype Park station.

With respect to safety, the problems are unique and not (at least explicitly) represented in the accident models. Some of the safety problems affect vehicle-to-vehicle accidents, which are not included in the analysis and for which no data have been collected. It is assumed that most grade crossings (the data from which are used to construct the accident models) do *not* have local traffic problems similar to those at NHP. Hence, the base case for ICS evaluation lacks these safety problems as well as the delay problems.

Many of the relevant features of the street network in the neighborhood of the crossing are shown in Figure 19. The larger buildings close to the LIRR tracks are commercial/industrial buildings, typically one or two stories with flat roofs. The smaller buildings are residential structures, primarily single-family dwellings. Jericho Turnpike is a heavily commercial thoroughfare, and buildings along and south of this arterial are not shown in the drawing. Pavement markings and signage are standard, and not all signs are shown. One-way street designations serve to smooth flows around the LIRR station, and prevent left turns into 2nd Avenue that would block the crossing.


Jericho Turnpike
SPEED LIMIT 30
NO TURN ON RED
South 16th St
South 17th St
South 18th St
South Park Place
ONE WAY
ONE WAY
Plaza Ave
ONE WAY
Plaza Ave
R R
Herkomer St
DO NOT STOP ON TRACKS
NEW HYDE PARK
GARDEN CITY
2nd Ave
ONE WAY
New Hyde Park Station (LIRR)
Hathaway Drive
Greenridge Ave
SPEED LIMIT 30
BUMP
R R
Clinch Ave
4th Ave
South 14th St
New Hyde Park Rd
Lincoln St

sources: Nassau County Department of Public Works; aerial photography from NYSGIS (http://www.nysgis.state.ny.us/).

Figure 19. Street alignment, pavement markings, and signage near the NHP crossing.

The most evident traffic problems are the following:

(1) Southbound traffic on New Hyde Park Road (NHP) is permitted to turn left onto Clinch Avenue, just below the crossing. Clinch Avenue is a direct connection to the next major east-west arterial to the south, and is used as a shortcut for traffic heading east. Especially during peak periods, a small share of vehicles making left turns onto Clinch can block one of the two southbound lanes on NHP, effectively reducing the capacity of NHP at the crossing and potentially backing traffic over the crossing. All four traffic lanes are 10' wide at the crossing, so there is no room for squeezing by a stopped vehicle without occupying the adjacent lane.

(2) Southbound traffic caught in the left-hand lane blocked by a turning movement onto Clinch often shift into the right lane suddenly, but especially so if they are on the crossing. This is common behavior on most multi-lane arterials, but the tendency to shift lanes without warning is exaggerated by the presence of the crossing.

(3) The large amount of paving at the intersection of NHP, Clinch, Greenridge Avenue, and Hathaway Drive is attractive to those drivers seeking a place to perform a U-turn. This is an additional source of delay for vehicles and reduction in the capacity of NHP, and also causes following vehicles to underestimate when space will open up and instead leaves them stuck on the crossing.[41]

(4) Although NHP is posted for 30 mph within the region of the crossing, traffic often moves much faster. Speeds were not systematically recorded, but a few random checks with the radar gun showed frequent spot speeds of over 40 mph, and these were well below the fastest speeds observed, estimated to be close to 50 mph.

(5) The crossing is raised somewhat above the normal road surface, prompting road signs for "bump" ahead. Due to the speed of much of the traffic, cars and single unit trucks were frequently observed with the tires of one axle entirely off the ground. While this happens after a vehicle has passed over the crossing, there is some loss of control and potential for vehicular accidents.

(6) Many of the businesses adjacent to the LIRR tracks are served regularly by combination trucks. Trucks heading north on NHP and turning into Plaza Avenue east of NHP, or coming out of Plaza Avenue, require both lanes to complete the move. Thus it is easy for northbound NHP traffic to back up over the crossing, from turning movements either east or west onto Plaza Avenue.

(7) When trains are operating at speeds well below maximum (perhaps due to equipment failure or other operations problems), vehicle queues can build up quite rapidly. A critical threshold occurs when traffic cannot enter NHP from

---

[41] In the portions of the two days when traffic was directly observed by the study team, a tractor-semi-trailer combination truck attempted to make a U-turn at this intersection, but was unable to do so in one movement. Another combination truck a few cars back proceeded onto the crossing on the assumption that the first truck had successfully completed its expected left turn. At this point the bells and flashing lights of the crossing control came on, and the second truck began honking urgently. The truck managed to clear the crossing, but the gate arms came down on top of the trailer.

Jericho Turnpike, thereby creating delay for traffic moving east and west on Jericho.

(8) Some vehicles—most of which are single unit trucks and small buses—stop at the crossing even though the gates are raised. Presumably this is a result of company policy that requires operators to stop and "look both ways" before entering the crossing, for safety reasons. The policy is unlikely to improve safety, may worsen it, and reduces throughput.

(9) Driver behavior appears to be generally reasonable, and most drivers are aware of the requirements of stopping when the lights start flashing and not entering the crossing when the exit is blocked by traffic. There are exceptions to this pattern, however, and the presence of the crossing creates additional pressures on drivers. When a driver's perspective is abruptly shifted from being on a street to being perpendicular in the middle of a railroad—very straight, on which the headlights of trains can be seen more than a mile away, and trains are known to travel at 80mph—the experience can be disorienting.[42]

Intersection Redesign

Most of the above problems could be dealt with at some cost, but eliminating them entirely—to the extent they are implicated in the grade crossing—would require grade separation. One group of problems ([1] through [3]), however, might be substantially mitigated through geometric design alone. These problems are those associated with the NHP intersection with Clinch Avenue.

The strategy for redesign would be to move the intersection farther to the south, consolidate the three entering roads (Clinch, Greenridge, and Hathaway) into a single connection, and greatly reduce the amount of paving. The area adjacent to the intersection is parkland not occupied by dwellings, although the space is not especially usable because of the way it is fragmented by paving.[43] An alternative is proposed in Figure 20. The circular drive serves no evident purpose and could be eliminated. The entrance to Hathaway and Greenridge, both of which are lightly traveled, could be reduced and consolidated. The intersection with NHP would be moved away from the crossing and made perpendicular, thereby reducing the extent of traffic queuing that extends over the crossing, and at the same time discouraging the use of Clinch as a shortcut. The design would move some (of the greatly reduced) paved area closer to two residences, but not closer than existing pavement. The consolidated green space could be landscaped and otherwise improved to be visually appealing and perhaps suitable for strolling and sitting if desired.

Whether a traffic signal should be installed and whether a left-turn lane can be included in the new design have not been explored. A traffic signal at the location of the current intersection would be within the 200-foot distance requiring an intercon-

---

[42] At one point during two days of direct observation, a train waiting for another train to pass was apparently standing on the approach circuit to the NHP Road crossing, causing the gates to operate erratically. Drivers, who up to that moment had been restrained and compliant, immediately perceived a malfunction and began driving through and around the gates.

[43] Ownership of the land has not been investigated.

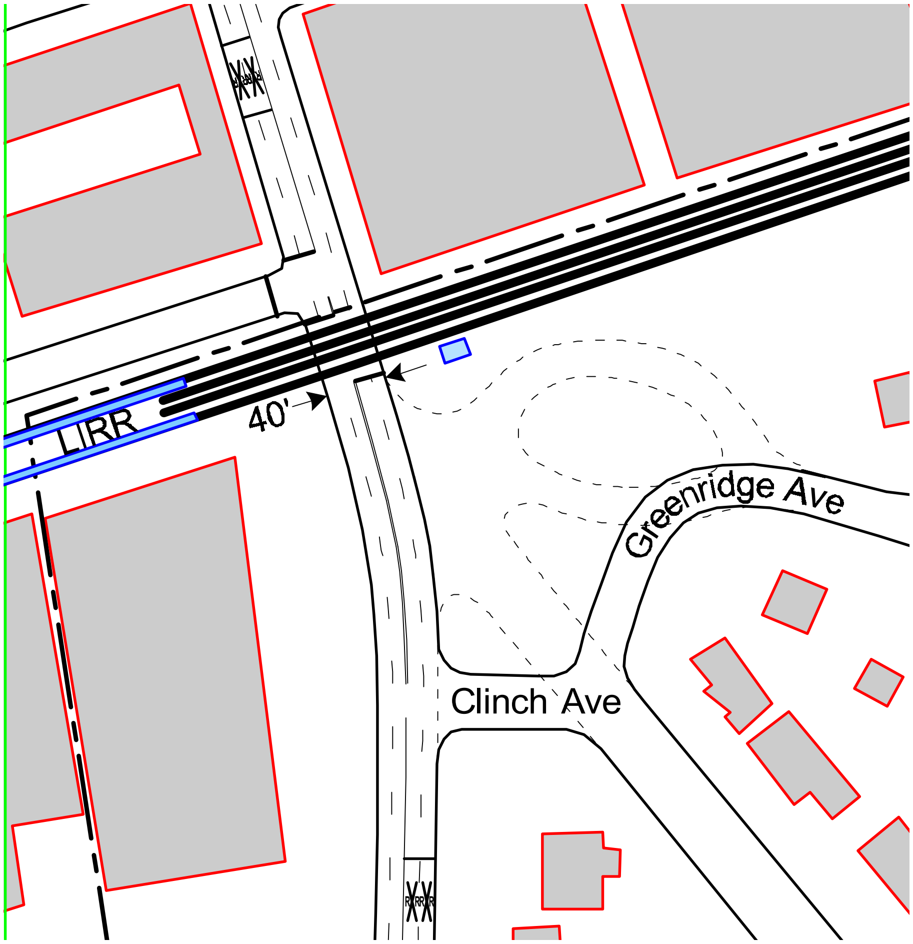


Figure 20. Possible reconfiguration of the NHP/Clinch intersection.

nect with the railroad crossing, but the relocated intersection would be outside that range.[44] Solving this intersection would involve the joint efforts of Nassau County (responsible for New Hyde Park Road), Garden City (responsible for local streets south of the LIRR and east of NHP), the LIRR, and probably New Hyde Park Village.

Based on the limited field data collection conducted for this study, the Clinch Avenue intersection reduces the capacity of NHP Road by 50% during peak periods, not only from blocking one lane during a large share of the peak, but also by reducing speed in the remaining southbound lane and disrupting northbound traffic. From manipulating the capacity parameter in the vehicle queuing models, the potential delay savings from fixing this intersection are estimated at $117,478 per year, not counting any safety benefits.

---

[44] Although the MUTCD recommends preemption within 200', other guidance recommends that a traffic signal that would cause expected queue length to be greater than the storage area, or exceed the storage more than 5% of the time, should be considered for interconnection (FHWA, November 2002).

Synthesis and Conclusions

This section takes the unit impacts estimated in the previous section and expands them to an annual and project-life basis. At the same time, ways to achieve some of the same benefits without implementing the entire ICS are described.

Aggregation of Benefits

Mapping of Actions into Benefits

Table 2 on page 8 provided an indication of how actions taken as part of the ICS would match up with benefits in comparison to the base or do-nothing alternative. A more precise mapping is shown in Figure 21 (omitting most intermediate linkages). Vehicle delay reduction comes directly from CWT, local traffic management, and emergency vehicle preemption, and indirectly from reducing crashes. CWT and VMS

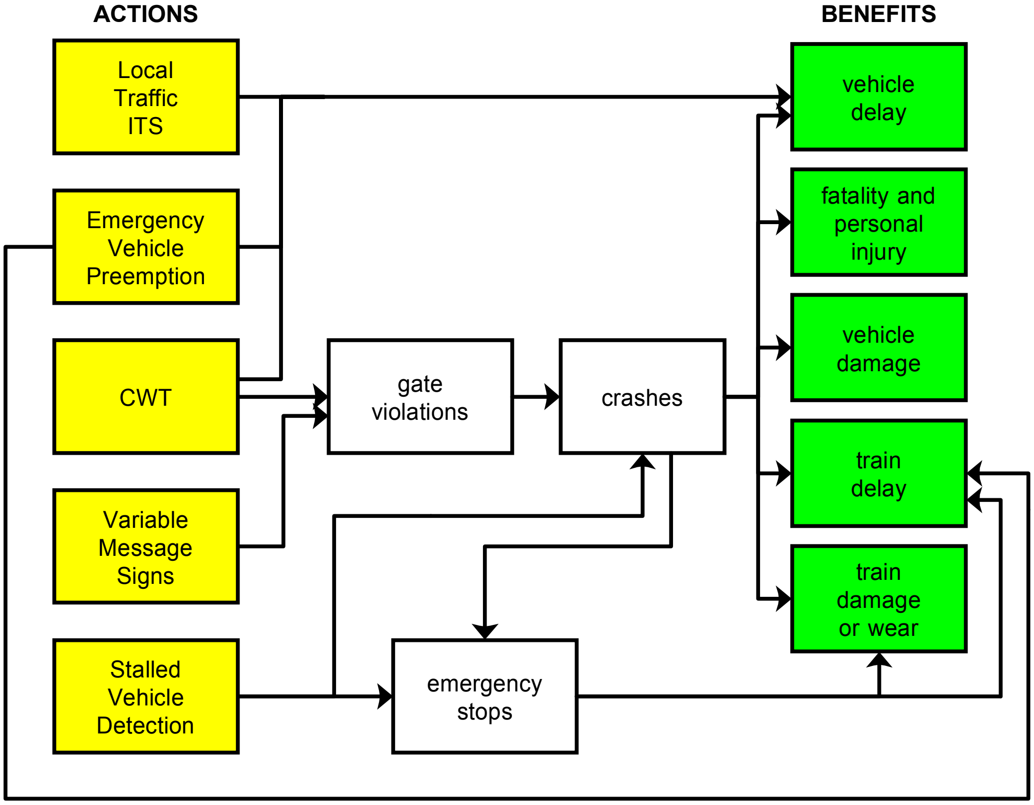

ACTIONS
BENEFITS
Local Traffic ITS
Emergency Vehicle Preemption
CWT
Variable Message Signs
Stalled Vehicle Detection
gate violations
crashes
emergency stops
vehicle delay
fatality and personal injury
vehicle damage
train delay
train damage or wear

Figure 21. Mapping from actions to benefits.

reduce gate violations, which reduces crashes and emergency stops. Stalled vehicle detection reduces crashes and emergency stops. Actions are shown on the left in the diagram, and benefits on the right. Impacts flow through the arrows.

Methodology

The models outlined above for estimating impacts of the several features of the Intermodal Control System apply at the per-event level (e.g., each gate closing). At that level, the impacts depend upon a number of parameters (e.g., traffic volume). These parameters are not constant, but vary over time (e.g., diurnally). Several strategies can be applied for aggregating benefits over variations in the parameters:

(1) Integrate (mathematically or by simulation) over all time periods and associated variations in the parameters;

(2) Select a small number of prototype scenarios, and treat each one as if the parameters were constant for the applicable time period; or

(3) Estimate an average value for each parameter, for a single overall scenario.

Strategy [1] would provide the most accurate results, if all interrelationships could be specified in full detail, but at the cost of considerable effort and "black box" inscrutability. Strategy [3] amounts to a "back-of-the-envelope" level of analysis, suitable if only very rough averages are needed for both parameters and results. When knowledge of the problem context is sufficient to allow recognition of important distinctions (e.g., peak vs. off peak train and vehicle volumes that cause much different delay levels), then approach [2] is a good compromise, and the one followed here.

Prototype Scenarios

A set of seven scenarios intended to represent the range of expected conditions is described in Table 20. Full-speed through trains with high traffic volumes create the highest accident risk, while high traffic volumes and slow or stopping trains generate the most vehicle delay.

Table 20. Prototypical scenarios for aggregating benefits

Scenario #	Type of Train	Time of Day	Speed Category	Speed (mph)	Train Passengers	Traffic Volume (veh/hr)	Trains Per Day
1	Through & Far-side Stopping Commuter Trains	Peak	Low	38	2,321	1,110	20
2	Through & Far-side Stopping Commuter Trains	Peak	Medium	63	1,487	1,110	13
3	Through & Far-side Stopping Commuter Trains	Peak	High	74	2,230	1,110	19
4	Through & Far-side Stopping Commuter Trains	Off-Peak		74	2,357	894	94
5	Nearside Stopping Commuter Trains	Peak		40	1,002	1,110	6
6	Nearside Stopping Commuter Trains	Off-Peak		55	645	894	13
7	Frieght/Maintenance/Construction Trains	Night		45	-	102	30
					10,043	6,330	195

To construct this table, the day is taken as the unit of analysis, i.e., all days in the year are alike. Hours of the day are divided into peak (6 hours), off peak (12 hours), and night (6 hours), and trains and train passengers are apportioned to those periods on the basis of schedules provided by the LIRR. Weekday and weekend schedules are weighted to calculate the average number of trains and passengers per day at New Hyde Park. Scenarios with high average train speeds generate only small time savings under the ICS because the through trains travel at the maximum speed, resulting in a relatively constant warning time. Far-side stopping trains are not affected by the ICS since most of the time they do not block the grade crossing, and for the times they do block the crossings the ICS would have no affect.

The seven prototype scenarios outlined in Table 20 were developed based on data collected during a two day site visit to the New Hyde Park grade crossing. Data such as train speed, train direction, gate down time, dwell time, and vehicle counts were collected for two PM peak periods, one AM peak period, and one off-peak period. During these observed periods, the trains speeds varied between 26 and 80 mph. By analyzing this data, it became clear that the speeds clustered into three major groups as shown by the colors in Figure 22. The observed shares of trains in each of these three different speed categories (High, Medium, and Low) were used to define scenarios 1, 2, and 3 and the volume of trains in each category.

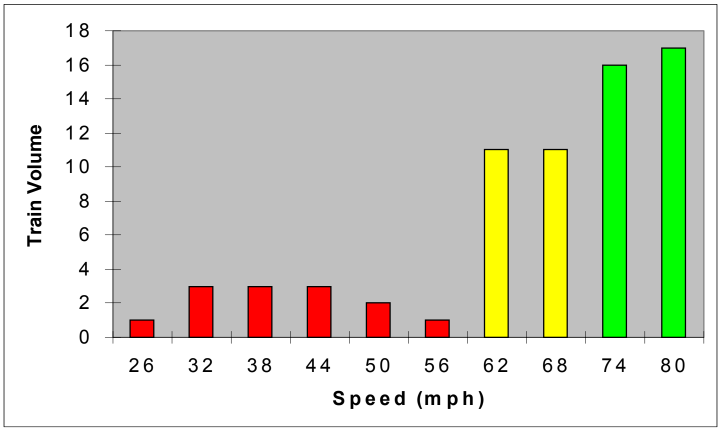


Figure 22. Histogram of Train Speeds

During the time periods where data were collected, the railroad system was functioning ideally. The gate down times were very close to uniform, and the queues that did build at the crossing were usually able to completely dissipate before the next crossing closure. Upon arrival at the crossing, however, the team observed approximately 15 minutes of continuous gate down time, which had a major impact on the traffic on nearby streets. Unfortunately, the team could not collect systematic data on these events (being stuck in traffic). It was later learned that the delay was caused by a broken rail on one of the tracks. This rail break forced all inbound and outbound trains to use a single set of tracks. Subsequent train speeds were greatly reduced until the system returned to the ideal state. Even though this situation is not a common occurrence, its extreme impact requires that it be modeled separately in the allocation of train volumes to speed categories (or scenarios).

To incorporate this phenomena into the model, a parameter was created which represents the probably of the system entering a compromised state. When the system enters a compromised state, the train speeds of all trains are greatly reduced and can be grouped in the low speed category rather than the medium or high speed category. By applying this probability to the compromised state (all trains in the low speed category) and the opposite probability to the ideal state (see Figure 22), a weighted average of train volumes per scenario was calculated.[45]

Benefits by Type of Benefit

The purpose of looking at the components of overall benefits is to observe which types of benefit are most important; large magnitudes may be subject to large implicit error if they are sensitive to uncertain parameters, whereas some benefit magnitudes may be insignificant no matter what parameter values are used.

Vehicle Delay

Vehicle delay is affected by CWT, emergency vehicle preemption, and local traffic management. The aggregation is done according to Figure 23.

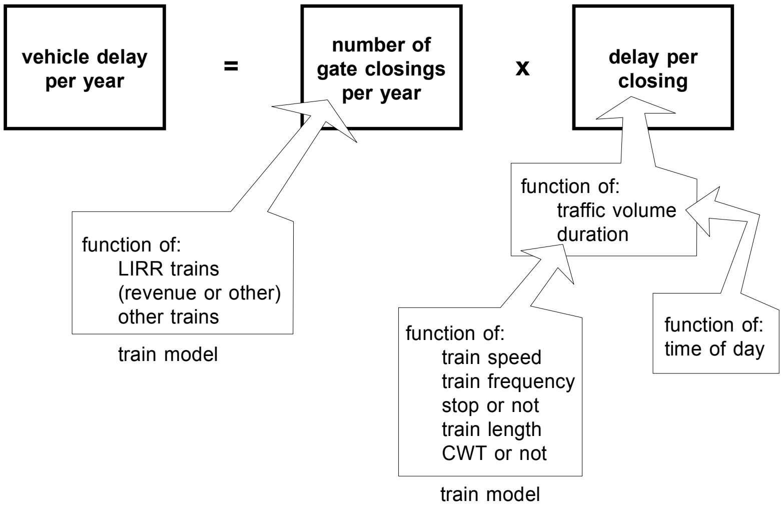

vehicle delay per year
=
number of gate closings per year
x
delay per closing
function of:
LIRR trains
(revenue or other)
other trains
train model
function of:
traffic volume
duration
function of:
train speed
train frequency
stop or not
train length
CWT or not
train model
function of:
time of day

Figure 23. Aggregation of vehicle delay savings.

---

[45] The compromised situation probability parameter is used to estimate the annual distribution of train volumes into the previously defined speed categories. The LIRR has the ability to collect the train speed data for all trains on an event recorder located at the grade crossing. In order to generate an adequate sample, downloading the data has to be repeated every couple of days due to data storage limitations. A reasonably large sample could, however, be used to directly estimate the shares of trains in each speed category, which would eliminate the need for the probability parameter.

Benefits from reducing vehicle delay depend upon the number of trains per year and the value of travel time. The valuation of travel time includes all occupants in the vehicle. Annualized results for each scenario are shown in Table 21, and they assume no gate violations. The vehicle delay benefits for emergency vehicle preemption and local traffic management are independent of the scenarios and were estimated in their respective sections. Thus the vehicle delay benefits are collected from each of the supporting models previously discussed, namely:

Table 21. Vehicle travel delay benefits from CWT.

	Base Vehicle Delay					**CWT Vehicle Delay**					**Savings**	
Scenario #	2-train events	single-train events	delay per 2-train event	delay per 1-train	total annual delay (hours)	2-train events	single-train events	delay per 2-train event	delay per 1-train	total annual delay (hours)	Annual Delay Savings (hours)	Delay Savings ($)
1	1.06	18	0.48	0.37	2,587	0.70	18	0.24	0.08	610	1,976	$45,275
2	0.68	11	0.48	0.13	669	0.45	12	0.24	0.08	391	278	$6,367
3	1.02	17	0.48	0.09	764	0.67	18	0.24	0.08	587	178	$4,071
4	4.76	85	0.49	0.07	3,046	3.08	88	0.24	0.06	2,240	806	$18,472
5	-	6	3.20	1.36	3,079	-	6	0.40	0.08	185	2,894	$66,294
6	-	13	2.21	0.87	4,025	-	13	0.36	0.06	285	3,740	$85,678
7	0.71	29	0.04	0.02	194	0.71	29	0.03	0.01	67	127	$2,917
					14,364					4,365	9,999	$229,074

- Constant Warning Time benefits in Table 21 on page 47
- "Emergency Vehicle Preemption of the Grade Crossing" on page 33
- "Local Traffic Management" on page 36.

Collision Reduction Benefits

CWT and VMS are estimated to reduce the frequency of crashes; costs of crashes include human fatality and injury, vehicle damage, train damage, and vehicle and train delay. Also included for convenience are costs of near-crashes (near misses) as reflected in reduced emergency braking events.

Rather than comparing two cases—an action scenario with its base—as is done with vehicle delay, collision reduction benefits are estimated using a base accident level and an effectiveness rate, as in

$$\text{collision reduction benefit} = \text{baseline accident rate} \times ER \times \$/\text{crash} \qquad [7]$$

where ER = effectiveness rate for the relevant treatment and base, from Table 11 on page 26, and \$/crash = unit crash cost from Table 16 on page 29. The first two terms (base rate times the effectiveness rate) give the change in the number of crashes per year, or "delta," resulting from the treatment or action. The result is benefits per year from reduced crash costs. Collision reduction benefits are shown in the second column of Table 22.

Benefits Tabulated by Action

The purpose of tabulating benefits by action is to see which actions are most productive (even before looking at costs), and to assess whether the actions can be separated and implemented in parts rather than as a single project.

Full Deployment

In these calculations, the actions are assumed to be taken in conjunction with each other. Thus, for example, the benefits from stalled vehicle detection, emergency vehicle preemption, and VMS all assume that CWT is also implemented (see Figure 21 on page 43). In some cases, these benefits can be obtained without implementing them all together. In some of these, the benefits will be greater if implemented without CWT because CWT reduces the base from which the benefits are measured (see "Incremental Implementation" on page 49).

Table 22. Benefits tabulated by action and type of benefit

Action Type	Vehicle Delay Benefits	Collision Reduction Benefits	Total
Constant Warning Time	$229,074	$193,865	$422,939
Variable Message Signs	-	$80,777	$80,777
Stalled Vehicle Detection	-	$32,311	$32,311
Emergency Vehicle Preemption	$25,936	-	$25,936
Local Traffic ITS	-	-	-
Total	$255,010	$306,953	$561,962

Although there are some important traffic problems affecting the grade crossing, they do not require ICS/ITS treatment, and there are no traffic signals located so as to be useful for mitigating the impacts of the crossing, so estimated benefits are zero (see Appendix J: "Facilitating Local Traffic With ITS" on page 105).

Benefits Cross-Tabulated by Action and Benefit

The vehicle delay and collision reduction benefits are tabulated in Table 22 by the action producing the benefits as well as the type of benefit. Annual (or annualized) benefits from reducing vehicle delay and train-vehicle or train-pedestrian collisions by the application of some kind of CWT system are substantial. When combined with the additional benefits of variable message signs and stalled vehicle detection, the total is close to half a million dollars per year.

The numbers in the table are given a misleading level of precision, derived as they are from quantitative models that perform arithmetic calculations without consideration of likely uncertainty and error. The models are all parametrized so that the sensitivity of the results to ranges of plausible values can be explored. Obviously, some variables—e.g., train and vehicle traffic volumes, the vehicle capacity of the crossing, and variability in train speeds—are much more important in driving the magnitude of benefits than are others.

Incremental Implementation

The ICS can be treated as a single package and evaluated as a single choice, or the ICS can be broken into a set of components that can be implemented in many combinations. The primary choices are shown in Figure 24. Incremental implementation considerations include:

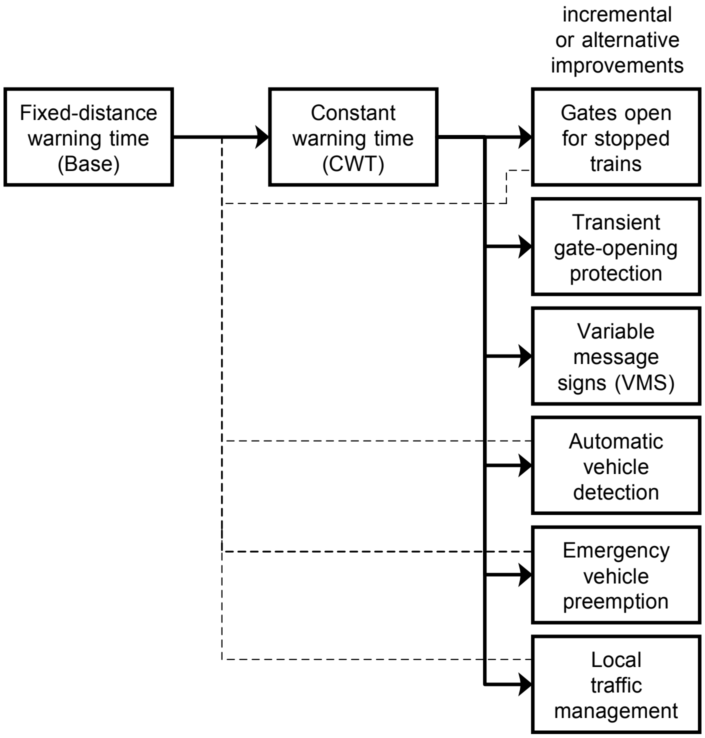

incremental
or alternative
improvements
Fixed-distance warning time (Base)
Constant warning time (CWT)
Gates open for stopped trains
Transient gate-opening protection
Variable message signs (VMS)
Automatic vehicle detection
Emergency vehicle preemption
Local traffic management

Figure 24. Hierarchy of incremental benefits.

(1) Keeping gates open for stopped trains could be accomplished with stand-alone technology (dashed line) or using the CWT train detection technology.

(2) Transient gate-opening protection could be implemented without CWT, but would offer little benefit (if based on block control) and would be difficult to accomplish; hence it is not evaluated as an independent action.[46]

(3) VMS depend upon information generated by the train detection system (whatever technologies used) and would have little or no beneficial effect without such information (e.g., how soon a train will arrive). Therefore deployment of VMS without CWT is not evaluated.

---

[46] A possible exception for VMS deployment would be to allow gates to remain up while a train is in the station (closer than 500 feet to the crossing), but warn motorists that they will see the train nearby when they enter the crossing. See footnote 11 on page 12

(4) Vehicle detection could be applied without CWT, but would be less effective without the accurate train position information, communications and control system (as reflected in the effectiveness rates, Table 11 on page 26).[47]

(5) Emergency vehicle pre-emption could be implemented without CWT, but with difficulty; with CWT, however, the benefits would be less because the crossing would be open a larger share of the time.

(6) Local traffic management using ITS could be implemented without CWT, but would be less effective without more precise information about train arrivals. Local traffic problems not amenable to ITS treatment (i.e., problems that can be addressed independently of the ICS) are assumed to be already solved in the base alternative, for evaluating the ICS.

Thus there are several ways to implement the individual functions of the ICS technology, and some combinations of components may be more effective than others. Table 23 shows the benefits of each of the incremental improvements if applied to the base case and, alternatively, if applied in addition to constant warning time. In each case the benefits are independent so any combination of incremental improvements could be applied and the benefits would be additive.

Table 23. Incremental improvement benefits

Incremental Improvement	Full Deployment	Incremental Implementation
Gates opened for stopped trains	$151,971	-
Stalled vehicle detection	$32,311	$26,926
Emergency vehicle preemption	$25,936	$65,301
Local traffic management	-	-

Alternative Ways to Obtain Benefits

The ICS is a comprehensive system for managing at-grade highway-railroad crossings, and generates a range of potential benefits because of its package of features. Many of the same benefits could be achieved separately, however, using more partial measures. Whether these devices are sufficiently fail-safe to operate vital crossing equipment has not been established. Also, the type of rail operation (e.g., electrified) may preclude the use of some technologies.

Vehicle Delay Savings. Vehicle delay savings stem from more accurate knowledge of where the trains are and how fast they are going, plus the capability of leaving the gates open while a train is stopped in the station. Other technologies short of ATC that could accomplish at least some of the vehicle delay benefits are:

(1) **Wayside Train Surveillance**. Several demonstration projects have applied non-intrusive sensing devices that detect trains and estimate their speeds.[48]

---

[47] Effectiveness rate are shown in Table 11 on page 26.

[48] See ITS Joint Program Office (2001) for brief descriptions of the San Antonio AWARD project and several VMS projects. The Moorhead, MN, project to detect trains and inform travelers is described in SRF Consulting Group (2000).

(2) **GPS On-Board Positioning**. GPS technology has become accurate and reliable enough to determine the position and speed of the front car and rear car of a train to a level that would substantially improve on conventional block control. The advantage of GPS is that it could overlay the base system for only those trains and crossings equipped to use GPS, without requiring system-wide capability before implementation. The Alstom system can also be implemented in this fashion (see Appendix G: "Constant Warning Time Technology" on page 91, and the ELSIE Final Project Report by Alstom).

(3) **Gate Time-Outs**. After a train has gone "dead" on an approach circuit for a sufficient length of time, it can be assumed to be stopped. With appropriate policies and controls, the crossing gates could be opened until the train is ready to start moving again. This might apply to trains stopping at stations or for track maintenance work.

These technologies are relatively inexpensive and could be deployed incrementally.

Collision Reduction. The deterrence of CWT combined with VMS could be very effective at reducing gate violations, but there are other methods that can have similar impacts:

(1) **Median Strips**. The difficulty of driving around a 2-quadrant gate can be increased by placing a raised median for some distance before the crossing on each approach. Some road width is required, some legitimate maneuvers may be prevented, and reflective signs need to be placed at the head of the median.[49] This treatment would be awkward at NHP because the lanes are only 10' wide, and the median would need to extend for some distance on either side of the crossing in order to avoid being a hazard.

(2) **Four-Quadrant Gates**. Adding two additional gates can prevent vehicles from going around the lowered gate arms (unless the vehicle is willing to break the arms, in which case it doesn't need to go around). Provisions need to

Table 24. Effectiveness rates for alternative crossing treatments

Supplemental Safety Measure	Effectiveness
4 quadrant - no detection	0.82
4 quadrant - with detection	0.77
4 quadrant - with 60' medians	0.92
Mountable curbs - with channelized devices	0.75
Barrier curbs - with or without channelized devices	0.80
One-way street with gate	0.82
Photo enforcement	0.78

source: FRA, *Federal Register* (2000); FRA (2002).

---

[49] See Mathieu (1993); Alroth (2001); FHWA MUTCD (2001)

be added to allow trapped vehicles to escape, and automatic vehicle detection is typically combined with 4-quad gates.[50] The effectiveness (see above “Effectiveness Rates” on page 24) of these measures has been estimated by FRA and the results are shown in Table 24.

Costs and Benefits

The above amounts to a first-cut estimate for evaluating the costs and benefits of improving train control and grade crossing control in an urban or suburban passenger railroad setting. Data obtained from the test site, combined with modeling and forecasting, could support evaluation of the system (in part or in whole) for application to a railroad branch, an entire railroad, or many railroads. Benefit-cost evaluation can take place in this way before systems are deployed, and used to monitor and adjust the actual performance of the system as it evolves.

Costs

As a single package, the ICS is not a standalone system: automatic train control and intelligent crossing controllers tied into the ATC would not be deployed for a single crossing. If systemwide ATC and IGC technology were being considered, then these costs should be compared with systemwide benefits. Such benefits would include not only the benefits at all grade crossings, but other benefits to train operations (such as schedule adherence) that are not considered in this study. Allocating systemwide costs to a single crossing is neither feasible nor meaningful.

A more suitable method for estimating costs is to assume the least cost technology for generating the specific benefits being evaluated, taking advantage of common costs where several actions can utilize the same capabilities (e.g., local traffic management depends upon anticipating gate closings). These costs are shown in Table 25. Initial costs are estimated for the components listed for the action, including labor for planning, installation, systems integration, and maintenance. The lifetime for all of the technologies is assumed to be five years, on average, at which point the systems would be upgraded or replaced. Using the lifetime and the discount rate in a capital recovery factor yields the annualized costs in the table.

The first “with CWT” column is based on implementing the CWT capability first, and using that technology to provide some information and communications used by the other features. Implemented together, the “Total” shows the estimated total cost. For those actions that can be taken without CWT, the somewhat higher initial costs are estimated in the second column. VMS has no value without CWT, so the cost is omitted; for stalled vehicle detection, the cost is no different with or without CWT.

Net Benefits

The costs are modest and the capabilities provide some benefits, so under the right circumstances all of the actions generate positive net benefits. But nor, however, are the benefits very large. Several observations may be pertinent:

---

[50] Hellman, Carroll et al (2000).

Table 25. Total and incremental costs for ICS features

	Initial Cost ($000)		**Annual Cost ($000)**		
Actions	with CWT	without CWT	with CWT	without CWT	**Components**
CWT (transient gates openings)	400	na	92		train detection, position forecasting, communications, processor
Nearside Stop Gates Open	50	80	12	18	communications, VMS, processor
VMS	120	not feasible	28		install signs, connect to train position information, processor
Stalled Vehicle Detection	80	same cost	18		install detectors, communications, processor
Emergency Vehicle Preemption	100	200	23	46	two-way communications, train information processing
Local Traffic Management	100	200	23	46	connection to gates, train information, signal controllers, timing plans
Total	850		196		
lifetime (years)	5				
discount rate	5%				

(1) If most through trains, especially those during peak periods, pass through the block (approach block plus island circuit) at 80 mph, and the approach circuit is located correctly, CWT is effectively maintained. No benefits—either vehicle delay or safety—are claimed in this study for through passenger trains.

(2) Benefits from leaving the gates open during nearside stops are already being achieved at some LIRR stations that are located at least 500 feet from a crossing. The technology for accomplishing this is simple and effective. The same solution perhaps could be applied at New Hyde Park with the addition of a VMS that would prevent motorists from being surprised at the nearness of a train.[51]

(3) With relatively constant warning time, other benefits are correspondingly small. There is little incentive for gate evasion, except perhaps during nearside stops and for pedestrians.

(4) The danger from gate evasion is primarily the presence of another train; this danger could be offset by a “second train coming” VMS.

(5) Emergency vehicle preemption of the crossing appears on its face to be relatively low on the list of possible actions that would reduce emergency vehicle travel time; others include real-time traveler information about congested locations and traffic signal preemption.

(6) The capacity of New Hyde Park Road appears to be fully adequate for its traffic volumes; hence, current levels of vehicle delay are kept within modest bounds and queues to not reach very far from the crossing. A higher volume-

---

[51] The LIRR says it gets complaints from motorists who enter a crossing and find a train uncomfortably close; the complaints tend to come from visitors unfamiliar with the area. Whether such persons would see a VMS if it were there, or what message would be effective, is not known.

to-capacity ratio would result in geometrically higher total vehicle delay levels and potential queue buildups.

Perhaps the most important lesson to be learned is that evaluation studies of the present sort ought to be undertaken before very much engineering design has been done and before anything is deployed or even field tested. This allows the problem to be defined and its critical parameters identified before a solution is proposed.

Distribution of Benefits

Benefits of the ICS are captured by participants in the project depending upon the type of impact; savings in vehicle delay at crossings are captured by highway vehicles, and reductions in train operating costs are captured by the LIRR. This distribution in shown in Table 26.

Although the railroad bears some of the costs of collisions (more if liability awards or insurance claims are paid by the LIRR), most of the benefits of reducing delay and accidents accrue to highway users. The LIRR does not charge highway users to cross the tracks, and has no way to translate highway user benefits into revenues. To the extent that benefits accrue to rail passengers, the LIRR cannot extract these benefits in revenues, such as fares. Thus the LIRR has little financial incentive to implement improvements that result in CWT, leave gates up during station stops, eliminate transient gate openings, inform highway users and pedestrians when the next train is coming, permit emergency vehicles to preempt the crossing, or improve local traffic management. The railroad has slightly more incentive to detect stalled vehicles before they are visible to the train operator. Avoiding crashes is in the railroad’s interest, but only a portion of the benefits are captured by the rail service provider. Reducing vehicle delay may have some benefits if expressed through the political process, given that the LIRR is a public agency.

From a theoretical perspective, the assignment of property rights is arbitrary: there is no more reason to give ownership of the crossing to the railroad than to the highway. If the railroad has prior claim (e.g., by buying the land first), then it could charge a toll to anyone wanting to cross the tracks. Alternatively, if the highway ROW preceded the railroad, the highway owner could charge the railroad for delaying traffic (instead of making trains wait for a break in traffic). Whichever way the ownership evolved, there would be an incentive expressed through a market mechanism to minimize delay to highway users consistent with safety and maintaining train schedules.[52]

In practice, of course, such a mechanism does not exist. If reducing vehicle delay is in society’s interest (i.e., the benefits exceed the costs), then a mechanism for financing the improvements needs to be worked out at a level higher than the LIRR or the local highway network.

---

[52] See Coase (1960).

Table 26. Recipients of Benefits.

Benefit	**Received By:**
reduce vehicle repair, injury and damage costs	HU
reduce highway incident clearance costs	HO
reduce delay from incidents	HU
reduce railroad repair, damage, and clearance costs	TO
reduce train delay from incidents	TP
reduce vehicle delay	HU
reduce hazardous vehicle movements	A
reduce emergency train stops	T
reduce travel time for emergency vehicles	HU
increase travel time for train passengers	TP
increase number of train stops	TO
increase train operating cost	TO
reduce uncertainty/anxiety for vehicle operators	HU
reduce pedestrian non-compliance occurrences	F
reduce pedestrian accidents	A
facilitate/impede street crossing by pedestrians and disembarking train passengers	F
manage traffic signals to minimize impact of grade crossing closure	HU
reduce vehicle delay	HU
store or guide vehicles to reduce non-compliance incentives	HU
Benefit Recipients: H highway users and operator HU highway users HO highway operator T train passengers and operator TP train passengers TO train operator F pedestrians A all of the above X benefits external to the above	

Appendix A: Study Background

The present study is the evaluation component of a project to develop an intelligent grade crossing system (called the ICS) that employed communications-based train control (CBTC) technology. The research project was funded by a grant from the Federal Highway Administration, and administered by the New York State Department of Transportation (NYSDOT).

Other Studies of Grade Crossing Technology

A group of studies was identified for review in 1997 (Polk, 2001) as applying intelligent transportation systems (ITS) technology to rail-highway at-grade crossings. Of those studies, the ones producing useful results include a pedestrian-transit crossing in Los Angeles (PB Faradyne, 2002), a transit-road crossing in Baltimore (Maryland MTA and Sabra, 2001), on-board vehicle warning devices (Illinois DOT, 1999), long and slow freight trains that bisect a city (SRF Consulting, 2000), and four-quadrant gates (Hellman et al., 2000). The studies were in the form of field operational tests (FOTs) of pilot or experimental deployments of previously developed technology, designed to demonstrate the feasibility of broader deployment.

The most ambitious of these studies was the design of an intermodal control system (ICS), aimed at high-density rail lines with at-grade highway crossings having relatively large volumes of traffic. The project was proposed by NYSDOT in conjunction with the Long Island Rail Road (LIRR), and the grade crossing and commuter-rail station at New Hyde Park Road was selected as a site suitable for displaying and testing the several capabilities of the ICS.

GRS/Alstom Contract

A contract was awarded to what was then General Railway Signal Corporation (GRS) for approximately $9 million to design the ICS and to provide simulations, models, and a field demonstration of the working technology. The results of that effort are contained in the 4-volume final report (Alstom, 2001). The field demonstration took place at 1AM in the morning of June 20, 2001. Trains were not in service, were not operated at full speeds, were operated manually rather than under automatic train control (ATC), and the gates were not under the control of the ICS (a small-scale physical model of the gates was operated instead of the real gates; see Alstom (October 2001), main text, p. 4). A prototype variable message sign (VMS) was set up on a side street and operated automatically by the ICS. No actual traffic control took place. Thus the test was primarily a demonstration of how selected aspects of the ICS would be expected to function if it were actually installed.

Project Deployment Evaluation

A requirement for all of the grade crossing studies was to conduct an evaluation of the particular technology deployed, in the actual context. Most of the studies went beyond demonstrating that the technology worked, and collected original data on performance before and after the deployment. Measures included gate violations, other risky behavior, and number of pedestrians crossing within X seconds of a train. In general, attempts were made to show an impact of the deployment, and deployment costs were tabulated, but none of the studies made quantitative estimates of benefits. The ICS is the only one of the group of studies that attempts to conduct a benefit-cost evaluation of the project.

The Volpe Center was selected to conduct the evaluation, and an inter-agency agreement was signed in July, 2002. Draft reports were delivered in January and June of 2003.

ICS Study Participants

Participants in the Intermodal Control System design include:

- New York State Department of Transportation (NYSDOT), Program Manager
- Federal Railroad Administration (FRA), Region 1
- Federal Highway Administration (FHWA), New York Division
- Long Island Rail Road (LIRR)
- Alstom Signaling, Inc. (formerly Sasib Railway, Inc., and General Railway Signal (GRS)), prime contractor
- Parsons Transportation Group (PTG)/ DeLeuw Cather, subcontractor
- RSE, subcontractor
- Kasten Chase, subcontractor for communications
- GEC-Alstom, subcontractor for the positioning system
- US DOT/Volpe Center, evaluation task

Operation

If implemented, the ICS would be operated by the LIRR. The system is intended to receive information from the highway system and provide information back to it. Participants in the operation include LIRR, Nassau County traffic operations, and authorized equipped emergency vehicles.

Appendix B: Train Speed Models

In order to estimate the length of time that the gates would be lowered under various scenarios (with and without CWT), it was necessary to develop some simple models of the time needed for a train to traverse various distances, whether traveling at a constant speed, accelerating, decelerating, or some combination.

Constant Velocity

The most fundamental equation relating time and velocity is

$$D = R \times T \qquad [8]$$

where D = distance, R = rate or speed or velocity, and T = time. If the unit measures are not consistent, then conversion factors are implied. For example, the distance traveled in feet at a velocity of 79 miles per hour for 30 seconds is

$$\text{distance (feet)} = 5280 \times 80 \times 30/3600 = 3{,}520 \qquad [9]$$

If equation [8] on page 59 is rearranged to show time as a function of velocity, for a fixed distance, then the equation plots as a rectangular hyperbola, as shown in the higher solid curve in Figure 25. This curve uses 3,476 as the distance, yielding time (in seconds) against velocity (in mph). The previously calculated point (velocity = 79 mph and time = 30 seconds) appears on the far right-hand side.

For the field demonstration staged by Alstom, a locomotive was run at various speeds ranging from 13 to 50 mph, and the time was measured to arrive at the island circuit from the beginning of the block, 3,476 feet away. These empirical data are plotted as *X*s in the diagram. Alstom then fitted a power function to the data by means of the least squares criterion, and derived the dashed curve labeled $t = 242.5\,(.965)^{s}$. This curve minimizes the vertical squared deviations from the points probably better than the theoretical curve, within the limited range of the data, but the theoretical curve is the “true” relationship. A small amount of error is introduced into the empirical data in that the locomotive did not maintain an exactly constant speed.

The lower two curves are similar, but both are entirely empirical. They simulate the time-to-arrival (warning time) by estimating the distance needed to provide 30 seconds of warning time. If the estimation were perfect, the line would be horizontal at 30 seconds. The solid curve is an arbitrary form selected for its conformance to the measured points, plus the theoretical point at 79 mph and 30 seconds, and for having a shape that curls up at the low end. The rationale for this is that at slow speeds, minor variations in speed have a relatively larger impact on estimated arrival time. The dashed curve fitted by Alstom omits the theoretical point and uses another power function as its functional form.

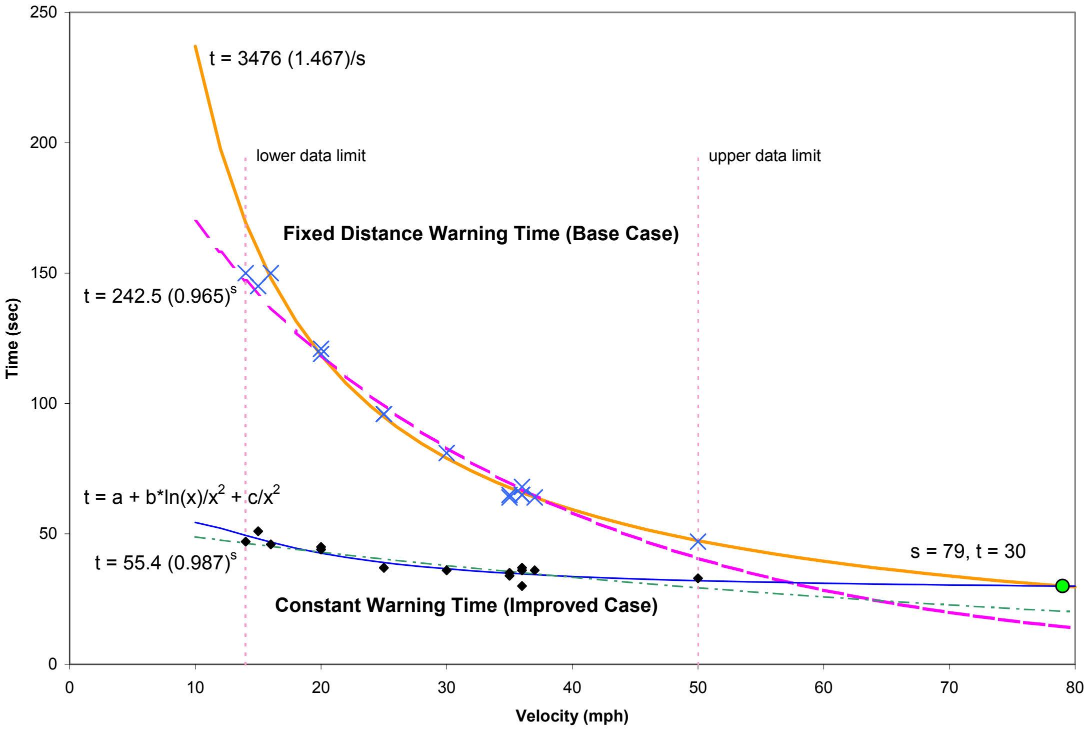


Figure 25. Warning time versus approach speed, with and without CWT.

Constant Acceleration

Another fundamental equation of motion is

$$v_t = v_0 + at \qquad [10]$$

where v_t = velocity at time t, v_0 = initial velocity, a = acceleration, and t = elapsed time. Again, inconsistent units among the variables requires conversion factors. Rearranging terms to calculate t, the formula can be used to calculate the time it takes a train traveling at 80 mph to reach a full stop when decelerating at a constant 1.73 mph/second:

$$t = \frac{v_t - v_0}{a} = \frac{-80}{-1.73} = 46 \text{ seconds} \qquad [11]$$

Although this is more than 30 seconds, it does not necessarily imply that the approach distance that provides 30 seconds of warning time is insufficient, i.e., the block may still be long enough so that the train could stop if there were an obstacle in the next block. To determine this, the stopping distance must be calculated.

Integrating equation [10] over time yields distance, as indicated by equation [8], in the form

$$D_t = v_0 t + \frac{at^2}{2} \quad [12]$$

where D_t = distance traveled over time t.[53] For examples, a train starting with an initial velocity of 80 mph and decelerating at 1.73 mph/second will require 2,713 feet to reach a complete stop.

Clearing the Island Circuit

The crossing gates come down when the train trips the approach circuit (in the base alternative), and they remain down until the rear of the train clears the crossing itself. For a through train, this is the length of the train plus the length of the island circuit, divided by the train speed. If 300 feet includes the train length and the width of the crossing, a train traveling 80 mph requires an additional time of

$$t_i = \frac{D}{v} = \frac{300 \times 3600}{80 \times 5280} = 2.6 \text{ seconds} \quad [13]$$

to clear the crossing.

Through trains traveling at less than the maximum speed

The length of the approach block to the island circuit must be long enough to provide the minimum required warning time for through trains, and also long enough to stop a through train if the crossing is occupied by a vehicle; whichever distance is longer governs. From the above calculations and for those parameter values, the warning time determines the location of the track circuit at the time of construction. Hence, as long as a train is traveling at 80 mph., there is no excess gate down time. For any speed less than 80 mph, however, there is some non-zero amount of excess gate down time. This excess down time can be calculated by

$$: ET_v = \frac{(3,520 + 300) \times 3600}{v \times 5280} - \frac{(3,520 + 300) \times 3600}{80 \times 5280} \quad [14]$$

where ET_v = excess time above minimum warning time, due to actual train speed, v, being below the permitted maximum.

Variable Acceleration and Deceleration

Using an average acceleration rate as if it were constant yields results that are probably satisfactory for estimating potential delay savings, but the estimates can be improved by recognizing the systematic relationship between velocity and acceleration.

Acceleration. If the station is at the end of the block, such that the locomotive is poised on the edge of the island circuit, the locomotive will need to travel the length of the train plus the length of the island circuit (300 feet for this analysis) to clear the crossing. The curve shown in Figure 8 (page 14) illustrates the acceleration rate of the train as a function of the velocity of the train. These data points can be used to create acceleration and velocity functions with time as the independent variable. The+- first step in this process is to fit a curve to the data shown in Figure 8. Using a software program called Tablecurve, the following function was fit to the data.

---

[53] This equation is most familiar in the form of $d = gt^2/2$, where g = the acceleration of gravity at 32 feet per second per second, and d = the distance an object will fall in a vacuum after t seconds from a stationary start.

$$A_a(v) = \sum_{i=1}^{5} \frac{a_i \cdot v^i}{(1 + b_i \cdot v^i)} \qquad \textbf{[15]}$$

Where

$$a_1 = 2.5062 \qquad b_1 = 0.00244$$

$$a_2 = 0.001389 \qquad b_2 = 0.01405$$

$$a_3 = 0.039109 \qquad b_3 = 0.00741$$

$$a_4 = 0.015358 \qquad b_4 = 7.75 \times 10^{-5}$$

$$a_5 = 8.2 \times 10^{-7} \qquad b_5 = 7.8 \times 10^{-7}$$

Using the stepwise evaluation method described below, the acceleration and velocity functions can be determined. At time equals zero, the train begins accelerating and the velocity begins increasing from zero.

$$\begin{aligned} t_{s+1} &= t_s + step \qquad t_0 = 0 \\ a_s &= A_a(v_s) \qquad v_0 = 0 \\ v_{s+1} &= v_s + a_s \times step \end{aligned} \qquad \textbf{[16]}$$

In this analysis the acceleration and velocity were computed at every half second. A smaller step size could be chosen to increase precision; however, the difference between step values of one second and half a second had little impact on the time estimates. Using a step size of 0.25 seconds resulted in a change on the order of a tenth of a second. With these new data points, Tablecurve was again used to fit a function to the velocity versus time data.

$$V_a(t) = \sum_{i=0}^{10} c_i \cdot t^{\frac{i}{2}} \qquad \textbf{[17]}$$

Where $V_a(t)$ = velocity at time t given acceleration a, and

$$c_0 = 0.00382 \qquad c_6 = 0.00454$$

$$c_1 = -0.8650 \qquad c_7 = -2.68 \times 10^{-4}$$

$$c_2 = 4.4079 \qquad c_8 = 6.84 \times 10^{-6}$$

$$c_3 = -1.2568 \qquad c_9 = 6.62 \times 10^{-8}$$

$$c_4 = 0.2784 \qquad c_{10} = -5.24 \times 10^{-9}$$

$$c_5 = -0.04435$$

This function for $V_a(t)$ was chosen because it is the best fitting polynomial function. It is important that $V_a(t)$ be integrable because this will allow $V_a(t)$ to be integrated to determine a function for the displacement $X_a(t)$.

$$X_a(t) = \sum_{i=0}^{10} \frac{c_i}{\left(\frac{i}{2}+1\right)} \cdot t^{\left(\frac{i}{2}+1\right)} \qquad \textbf{[18]}$$

Now that we have a function for the displacement as a function of time, we can set this function equal to 300 feet and solve for time. This results in a time of 18 seconds in order for the last car to clear the island circuit. It is also important to note that this portion of the analysis is independent of the constant velocity assumed (80 mph) since the train only reaches a speed of 20 miles per hour in the 300 feet that it is accelerating.

Deceleration. In contrast to the normal service braking policy described in “Deceleration” on page 12, actual rates for emergency stopping vary systematically with velocity.

For emergency stops, the wheels are locked and the train slides to a stop by steel wheels scraping on steel rails. This causes damage to the equipment and the tracks, and may result in passenger injuries. Full Service Braking is the shortest feasible stop without locking the wheels, and is estimated to be about 75% of emergency braking. Normal service braking is intended to provide maximum passenger comfort consistent with maintaining a reasonable schedule, and is slower than FSB. For estimating typical travel times, the normal braking curve is used.

Data for locomotive deceleration under emergency are shown in Figure 26. At speeds below about 40 mph, deceleration can take place at 3.5 mph/second, but at higher speeds a less aggressive deceleration is appropriate because dissipating the kinetic energy of the train requires more effort (note that the vertical scale begins at 2.5, not zero). The solution for time and distance is very similar to the process used when the train is accelerating. The curve in Figure 26 can be approximated very closely by fitting equation [19] to the data points in the graph,

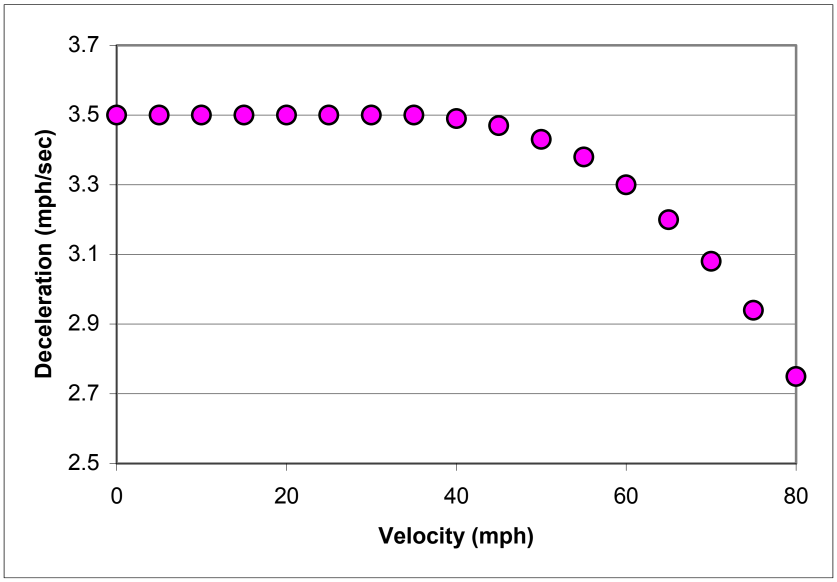


Figure 26. Deceleration as a function of velocity

$$A_d(v) = \sum_{i=0}^{7} d_i \cdot v^i \qquad [19]$$

where

$$d_0 = 24.875 \qquad d_4 = 1.155 \times 10^{-4}$$

$$d_1 = -3.0252 \qquad d_5 = -1.33 \times 10^{-6}$$

$$d_2 = 0.1811 \qquad d_6 = 8.3974 \times 10^{-9}$$

$$d_3 = -5.94 \times 10^{-3} \qquad d_7 = -2.24 \times 10^{-11}$$

Using the same stepwise evaluation process as before in [16], data points for the acceleration and velocity functions with time as the independent variable can be created. The only differences in the stepwise analysis are the initial conditions: $v_0 = 60$ and $t_0 = 0$. Equation [20] was fit to the velocity data, and integrated to determine the displacement function [21].

$$V_d(t) = \sum_{i=0}^{10} f_i \cdot t^i \qquad [20]$$

Where

$$f_0 = 88.00 \qquad f_6 = 1.96 \times 10^{-5}$$

$$f_1 = -4.8184 \qquad f_7 = -2.15 \times 10^{-6}$$

$$f_2 = -0.0465 \qquad f_8 = 1.28 \times 10^{-7}$$

$$f_3 = 0.00304 \qquad f_9 = -3.92 \times 10^{-9}$$

$$f_4 = 8.55 \times 10^{-5} \qquad f_{10} = 4.92 \times 10^{-11}$$

$$f_5 = -9.07 \times 10^{-5}$$

$$X_d(t) = \sum_{i=0}^{10} \frac{f_i}{\left(\frac{i}{2} + 1\right)} \cdot t^{\left(\frac{i}{2} + 1\right)} \qquad \textbf{[21]}$$

In this case, the velocity function can be set equal to zero and solved for time. Since this is a polynomial there are multiple roots; however, the one of interest is the smallest non-zero, non-negative value for *t*. This value turns out to be 17.3 seconds, which is the time required for the train to reach zero velocity from an initial velocity of 60 miles per hour. To determine the distance traveled in this time period, the function $X_d(t)$ need only be evaluated at t = 17.3 seconds. This results in the train traveling 766 feet in 17.3 seconds in order to stop at the train station. Assuming an initial velocity of 79 miles per hour, then 24 seconds and 1,403 feet are required for the train to come to a complete stop.

Appendix C: Vehicle Queuing Models

This appendix addresses the special case of two trains taking control of the crossing within a short span of time that does not allow the vehicle queue built up from the first train to be completely dissipated before the arrival of the second train.

Two-Train Events

When the arrival of the second train occurs during the transient gate opening period (taken here as 12 seconds), the gates do not open and the gates-down duration is extended to cover the second train. The conditions are represented in Figure 27. The total duration of the closing is greater than what the sum of the two closings would be if the trains arrived farther apart, and total delay is over 2.5 times greater (0.66 hours versus 0.26 hours for both trains separately).

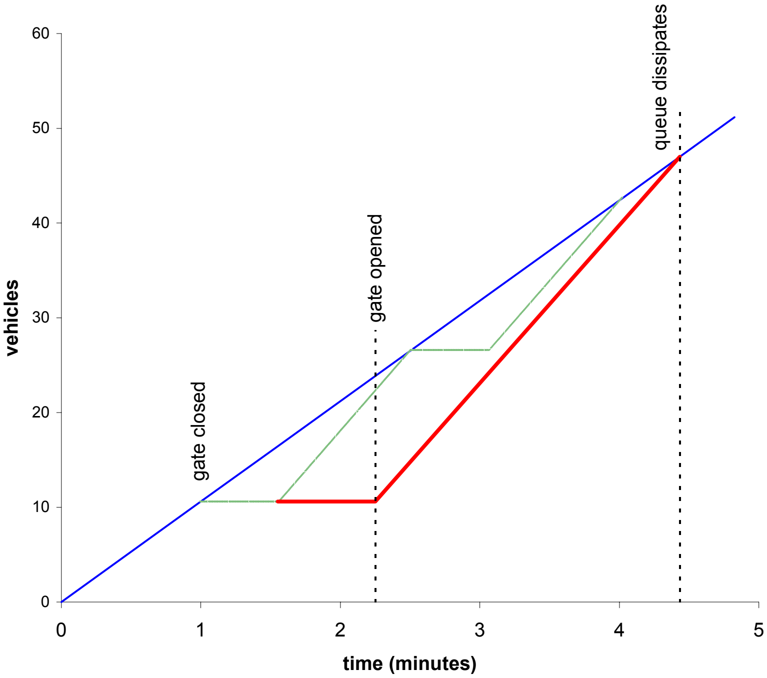


Figure 27. Two-train event invoking transient opening policy.

Once past the transient opening threshold (about 0.75 minutes after the 1st train, in this instance), total delay drops sharply and queue dissipation occurs at the same time as it would for back-to-back but separate events. What is happening is that the queue dissipates from the front, once the gates open, but the tail of the queue is still building up (the diagram assumes that the road starts flowing at capacity as soon as the gates go up). When the gates come down again, a new queue forms while the old one is still dissipating. A block of "open" (flowing) traffic moves backward through the queue, eventually snuffing out the first queue while the tail of the new queue chases after it. But because arrivals to the new queue are flowing at capacity (from pent-up demand in the old queue), no progress is made toward dissipation until the old queue is eliminated; then the normal dissipation rate takes over. Total delay is reduced, however, because some of the queue is released by the interim gate opening. The smaller delay is reflected in the area between the straight (blue) diagonal line and the envelope of the combined 1st plus 2nd (green plus red) closings.

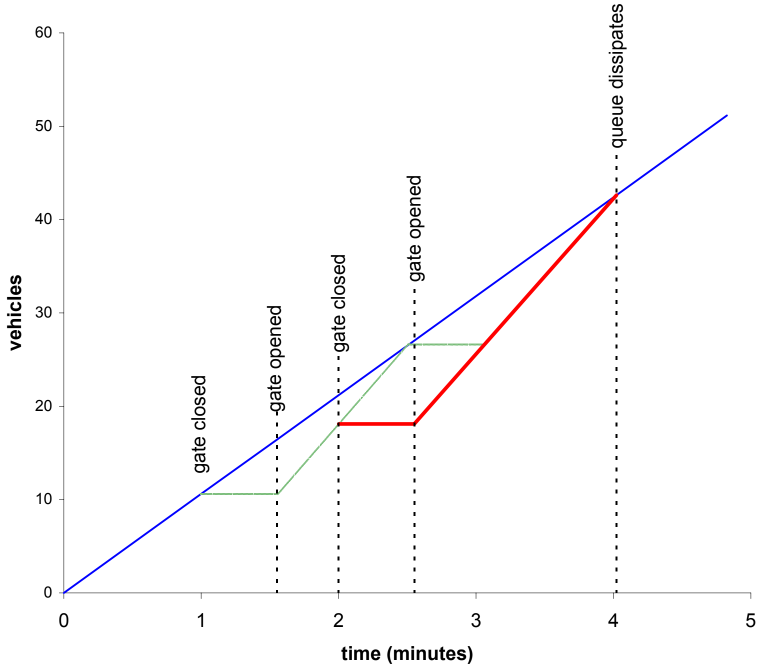


Figure 28. Two-train event with interim opening.

Total Delay and Maximum Queue Length

Two measures of interest—total delay in both directions, per event, and the distance of the tail of the longest queue from the crossing—are shown in Figure 29 as a function of the time between the arrival of the first train and the arrival of the second. When the two trains arrive at the same time (and cause the same closing duration), the distance of the queue from the crossing and the vehicle delay are the same as for a single closing (the left edge of the diagram). As the time lag increases, closing duration increases, up to the transient opening threshold. Queue distance increases linearly, because each increment of time adds the same number of vehicles—and therefore length in feet—to the queue. Delay increases quadratically, because queue length is multiplied by time, both getting longer with additional vehicles. After the transient opening threshold is passed, delay and queue distance drop suddenly because the gates are not closed if there is no train. Both then decline linearly because the queue buildup is simply reversed, but outflow at the capacity rate reduces delay faster than it builds at the arrival rate. At the right-hand edge, queue distance is back to the distance it started at, but the delay now includes both gate closings so is therefore twice what it was at the left edge. Only the major direction is shown.

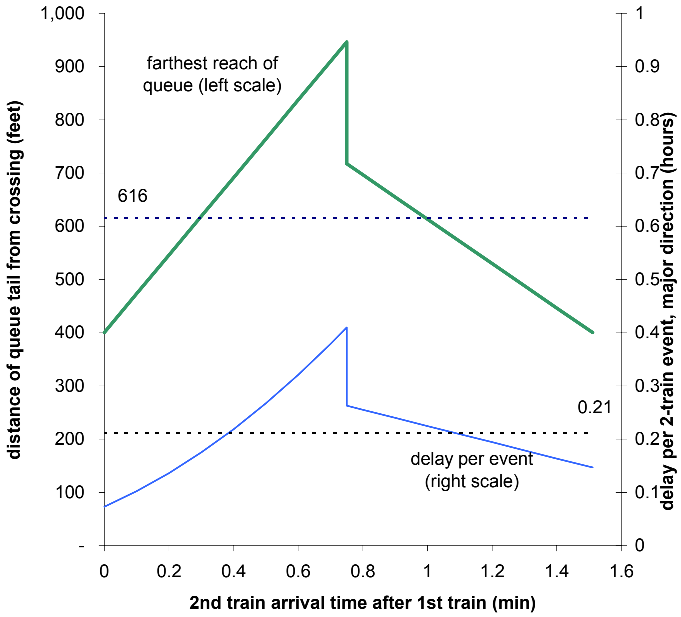


Figure 29. Queue distance and total delay, versus time between arrivals.

Because the probability of any particular lag time is uniform across the interval for which an overlap may occur (assuming randomness), the queue distance and delay can be averaged for all 2-train events, by dividing the area of each by the time interval. The result here is 616 feet and 0.21 hours.

Frequency of Two-Train Events

Trains going in the same direction are assumed never to be close enough to overlap in the sense that a train arrives before the queue from the previous train has dissipated. Thus all 2-train events result from trains going in opposite directions. Trains going in one direction can be imagined as occupying blocks of time (merged into a single block) represented by (the sum of) their closing times plus dissipation times. This share of a single hour is represented in Figure 30. The probability of a given train in the opposite direction overlapping any train going in the first direction is the ratio of the already occupied time plus the amount of time taken up by the new train, to the whole hour.

$$P_O = (N_{EB} + 1) \times Q \quad [22]$$

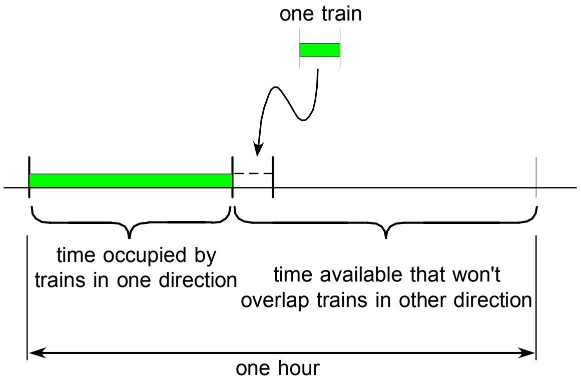

one train
time occupied by trains in one direction
time available that won't overlap trains in other direction
one hour

Figure 30. Probability of train overlapping with others.

where P_0 = probability that a single westbound train will overlap any eastbound train, N_{EB} = number of eastbound trains, and Q = queue time including both gate down time and dissipation time. The “1” in the formula allows for the non-zero space taken up by the westbound train (shown in Figure 30), which is the same as for each of the eastbound trains. Minutes are converted to hours, and the result is some fraction of an hour that can be interpreted as a probability.

The expected number of 2-train events in one hour is the probability of one westbound train overlapping an eastbound train, times the total number of westbound trains to be “placed.”[54] Finally, the expected number of 2-train events in the period (peak, offpeak) is the number of hours in the period times the expected 2-train events per hour, yielding

$$E_{\text{2-train events per period}} = HRS_{\text{period}} \times N_{WB} \times (N_{EB} + 1) \times Q \qquad \textbf{[23]}$$

where E = expected number of events, HRS_{period} = hours in the time period, and N_{WB} = number of westbound trains. Given the number of trains passing in one hour, half are presumed going in one direction and the rest in the other, so

$$N_{EB} = N_{WB} = \frac{N}{2} \qquad \textbf{[24]}$$

where N = total number of trains per hour during the period.

---

[54] This probabilistic strategy assumes independent trials, which allows the possibility for two trains in the new direction to overlap, and denies any relationship between the timing of one train and the probability distribution for the next train’s time, both of which are contrary to the real situation. The first is not a problem because no such overlaps, even if they occur, are counted anyway. The second simplification ignores the knowledge that if one train occurs in a given time slot, another in the same direction will not, which implies that timing in the two directions will tend to be “in phase” (match up) or “out of phase” (not overlap) as a group; this effect increases the variance, but does not change the mean.

Appendix D: Valuation of Travel Time

Travel time savings and costs occur in the benefit estimates for traffic delay savings, for collision costs, for emergency stops, for variable message signs, and for vehicle preemption benefits. The value of travel time is estimated for average vehicles, train passengers, and emergency vehicles.

Theory of Travel Time Valuation

A considerable literature has been generated on the theory and practice of measuring travel time value, but this has not led to agreement on either methods or numbers. By general consensus the starting point is the hourly wage rate, although this creates difficulties in valuing time of non-earners or the effect of household size and composition on how members value their time.

For highway travel, a common strategy is to estimate factors on the wage rate (from 20% to 100%) depending upon the purpose of the travel (work, commuting, recreation), with paid travel being valued at 100% of the wage rate and recreation at 20-50%. This implies that time is not “fungible,” i.e., it cannot easily be shifted, for example, between work and leisure. This strategy also implies that trip purpose serves as a surrogate for other factors not measured.

A somewhat divergent approach is to consider two components of travel time cost, namely,

(1) the *opportunity cost* of the time, which is the extent to which the traveler is prevented from doing what would be more preferred, whether leisure or work; and

(2) the discomfort or *disutility* value, such as whether the traveler is standing, comfortably seated, crowded, exposed to weather, etc.

Under this approach, a person’s underlying value of time is constant (still based on the wage rate or income level), and the cost of the time to the traveler is the extent to which s/he can use the time productively or enjoyably, and the disutility level. These two tend to move together, in that it is hard to use time productively when one is uncomfortable.

This leads to a model of the form

$$VOT_i = W_T \times (1 - U_i) \qquad [25]$$

where VOT_i = value of travel time in context *i*, W_T = average wage rate for travelers in this context (e.g., auto or rail passengers), and U_i = usability-disutility factor reflecting the degree to which travelers in this context can use the time for doing things they wish to do. If the time is fully usable for working or reading and these activities would be done anyway, then the usability factor is 1 (100%) and the opportunity cost of the time is zero; if the traveler can do nothing useful and is uncomfortable as well, then the usability could be negative and the cost of the time even greater than the wage rate. This strategy aims more directly at the willingness-to-pay of travelers to be shifted to situations where their choices are unconstrained.

Vehicle Travel Time

Most of the procedures used here for estimating the average value of travel time are taken from the HERS-ST model, which is maintained by FHWA for purposes of evaluating state and national highway investment requirements based on benefit-cost grounds.[55] The HERS model does not incorporate the usability factor, relying on the more traditional factors by trip purpose.

Vehicle Occupants. Wage rates for business travelers are updated (using price indices) from the 1995 values in the US DOT departmental guidance.[56] Data on the value of time per person are indexed from 1995 data using the U.S. Bureau of Labor Statistics (BLS) Employment Cost Index for total compensation of all civilian workers. The DOT numbers are the values for travel via surface modes. Wage rates for personal travel are updated here to use the median income of households and individuals ($41,994) from the 2000 US Census, dividing by 2000 hours per year.

Table 27. Wage rates for vehicle occupants

Type of Vehicle Occupant:	Wage Rate	Usability
Business Travel Driver	$22.17	20%
Business Travel Passenger	$22.17	30%
Truck Operator	$19.45	10%
Truck Passenger	$19.45	30%
Personal Travel Driver	$21.00	15%
Personal Travel Passenger	$21.00	25%

The usability factors are estimates of how much the in-vehicle time (delayed or not) can be used for preferred purposes. Passengers have somewhat more ability than drivers to do other things, and commercial occupants (other than truck drivers) are assumed to be slightly better prepared to use their travel time for productive purposes.

Average Vehicle Occupancy. Average vehicle occupancy (AVO) of four-tire vehicles is derived from the 1995 National Personal Travel Survey (NPTS)[57] along with estimates of VMT and person-miles of travel by trip type. The NPTS data indicate that AVO for "work-related business" (exclusive of commuting) is 1.43, while AVO for all other purposes is 1.67. Occupancy rates are believed to have declined since 1995, as reflected in Table 28.[58]

---

[55] *Highway Economic Requirements System State Version: Technical Report* (2003)

[56] U. S. Department of Transportation, "The Value of Saving Travel Time: Departmental Guidance for Conducting Economic Evaluations" (1997, updated), Table 4.

[57] Oak Ridge National Laboratories, *1995 National Personal Travel Survey*, Table NPTS-1, October 1997 (www-cta.ornl.gov/npts/1995/doc/table1.pdf).

Table 28. Value of time for highway vehicles

	Vehicle Class						
	small auto	medium auto	4-tired truck	6-tired truck	3-4 axle truck	4-axle combn	5-axle combn
Business Travel							
value per person[1]	$22.17	$22.17	$22.17	$19.45	$19.45	$19.45	$19.45
average occupancy	1.4	1.4	1.4	1.05	1.00	1.1	1.1
vehicle time cost[2]	$ 1.23	$ 1.65	$ 2.15	$ 3.00	$ 8.11	$ 7.27	$ 6.98
inventory time cost						$ 0.80	$ 0.80
Personal Travel							
value per person	$21.00	$21.00	$21.00				
average occupancy	1.2	1.2	1.2				
Percent Personal	89%	89%	75%				
Value of Vehicle Time by Vehicle Class	$22.55	$22.97	$23.89	$19.24	$23.67	$24.99	$24.70
Distribution within primary categories	0.1976	0.5998	0.2027	0.6590	0.3410	0.1765	0.8235
Shares by primary categories			86%		10%		4%
Average Value of Vehicle Time	$ 22.91						

For combination trucks, AVO was adjusted to 1.1 on the basis of Hertz' analysis of the frequency of the use of two-driver teams in crash-involved trucks.[59] Six-tire vehicles, which include pick-up-and-delivery vehicles that sometimes carry a helper, were assumed to have an average occupancy of 1.05, while heavier single-unit trucks were assumed to have only one occupant. Data on the vehicle cost and inventory-cost components are indexed from 1995 data using, respectively, the U.S. Department of Commerce Bureau of Economic Analysis (BEA) data on average expenditures per car, and the implicit gross domestic product (GDP) price deflator, also obtained from BEA.

Vehicle Costs. Vehicles depreciate as a result of their use and also as a result of aging that is independent of vehicle use. The former type of depreciation is estimated by the HERS-ST vehicle operating-cost procedure, while the latter type is a time-related cost incurred by all vehicle owners and included as a component of travel-time cost of commercial vehicle operators. The assumption here is that delay savings for commercial vehicles allows them to be used for additional travel.

For autos in commercial motor pools and four-tire trucks, total depreciation per hour was computed as the average vehicle cost per year (assuming a five-year life and a 15 percent salvage value at the end, with initial cost from the American Automobile Manufacturers Association[60]) divided by 2,000 hours per year of sign-out time (essentially the day shift or other shift when maximal vehicle use occurs). For heavier trucks, total depreciation per hour was computed as the average vehicle cost per year divided by the number of hours in service per year.[61] Six-tire trucks and four-axle combination trucks were assumed to be in service 2,000 hours per year; and five-axle

---

[58] In addition, the HERS model forces occupancy to be the same for personal and commercial travel, which is neither necessary nor desirable for the ICS evaluation.

[59] Robin P. Hertz, "Sleeper Berth Use as a Risk Factor for Tractor Trailer Driver Fatality," *31st Annual Proceedings, American Association for Automotive Medicine*, September 1987, pp. 215-227.

[60] American Automobile Manufacturers Association, *Motor Vehicle Facts and Figures, 1996*, Detroit, 1996, p. 60.

combinations were assumed to be in service 2,200 hours per year. Because three- and four-axle single-unit trucks include many dump trucks that have down time between jobs, especially during cold periods of the winter, they were assumed to be used only 1,600 hours per year.

The resulting estimates of total depreciation per hour of operation are shown in the first column of Table 29.[62] The relatively high value shown for three- and four-axle single-unit trucks is the result of the low number of hours per year that they are used and relatively small differences between the initial costs of these vehicles and those of tractor-trailer combinations.

Table 29. Estimation of Vehicle Costs (1995 Dollars)

Vehicle Type	Total Depreciation ($/hr.)	Miles per Year[a]	Mileage-Related Depreciation		Time-Related Depreciation ($/hr.)
			($/mile)	($/hr.)	
Small Autos	$1.72	11,575	$0.109	$0.63	$1.09
Medium/Large Autos	2.02	11,575	0.098	0.57	1.45
Four-Tire Trucks	2.18	12,371	0.045	0.28	1.90
Six-Tire Trucks	3.08	10,952	0.079	0.43	2.65
3+ Axle Trucks	8.80	15,025	0.175	1.64	7.16
3-4 Axle Combinations	7.42	35,274	0.057	1.01	6.41
5+ Axle Combinations	7.98	66,710	0.060	1.82	6.16

a. For automobiles, from Federal Highway Administration, *Highway Statistics 1997*, November 1999, Table VM-1; for trucks, from U. S. Bureau of the Census, *1992 Truck Inventory and Use Survey,* May 1995, Table 2a.

The second column of Table 29 shows estimates of average annual mileage for seven vehicle types. Annual mileage for automobiles is from *Highway Statistics*;[63] and annual mileage for the five categories of trucks is from the *1992 Truck Inventory and Use Survey.*[64]

---

[61] Estimates of average vehicle cost per year are those used in the *1997 Federal Highway Cost Allocation Study* (U.S. Department of Transportation, July 1997). Sources used in developing these estimates were: Jack Faucett Associates, “The Effect of Size and Weight Limits on Truck Costs,” prepared for the U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., 1990; Maclean Hunter Market Reports, *The Truck Blue Book*, January 1995, Chicago (sales prices for tractors and chassis); U.S. Bureau of the Census, *Current Industrial Reports, Truck Trailers*, summaries for various years (price adjustments for trailers); and a survey of truck dealers (prices for single-unit trucks).

[62] The table is taken from *Highway Economic Requirements System State Version: Technical Report* (2003).

[63] Federal Highway Administration, *Highway Statistics 1997*, November 1999, Table VM-1.

[64] Federal Highway Administration, *Highway Statistics 1997*, November 1999, Table 2a.

The third column of Table 29 shows the estimates of mileage-related depreciation, in cents per mile. The estimates of annual hours of operation presented above and those of annual miles per year shown in the second column of the table were then used to convert the estimates of mileage-related depreciation to dollars per hour (as shown in the fourth column); and this result was subtracted from total depreciation to produce the estimates of time-related depreciation that are shown in the last column of Table 29, and also (updated) in the third row of Table 28.

Inventory Costs. To compute the inventory costs for five-axle combination trucks, an hourly discount rate was computed and multiplied by the value of a composite average shipment. The discount rate selected was 9.8 percent, equal to the average prime bank lending rate in 1995 plus one percent. Dividing this rate by the number of hours in a year produces an hourly discount rate is 0.0033 percent. The average payload of a five-axle combination is about 35,000 pounds. In 1993, the average value of commodities shipped by truck was $1.35 per pound (on a ton-mile weighted basis).17 Inflating to 1995 dollars using the GDP deflator and multiplying by the average payload produces an average payload value of roughly $50,000. The resulting time value of the average payload is approximately $0.60 per hour (ignoring any costs for spoilage and depreciation over time).

Payload for four-axle combination trucks is lower than for five-axle combination trucks, but the value of the cargo probably is higher. Consequently, the value per shipment was assumed to be the same for both types of trucks.

Personal-Use Percentage of VMT. Approximately 4.7 percent of automobiles are estimated to be in commercial fleets of four or more vehicles, excluding fleet vehicles that are individually leased or used for daily rental;[65] and 6.7 percent of the VMT of the remaining automobiles is for work-related business.[66] These figures indicate that just under 89 percent of automobile VMT represents personal travel (including commuting), while the remainder represents business travel.

For four-tire trucks, the percentage of VMT that was not for personal use was 31 percent in 1992;[67] however, this percentage has undoubtedly dropped in the last several years as small truck-based vehicles have become increasingly popular as personal vehicles. Accordingly, personal use is assumed to account for 75 percent of the VMT of four-tire trucks and business use accounts for 25 percent of this VMT.

Distribution by Vehicle Class. Local section-specific data (for New Hyde Park Road) on the percentages of four-tire vehicles, single-unit trucks, and combination trucks are used for the primary vehicle categories, and these percentages are then allocated to the seven vehicle types using distributions (by functional system, urban minor arterials in this case) obtained from the HPMS Vehicle Classification Study.[68]

---

[65] American Automobile Manufacturers Association, *Motor Vehicle Facts and Figures, 1995*, Detroit, 1995, pp. 39 and 43.

[66] Oak Ridge National Laboratories, *1995 National Personal Travel Survey*, Table NPTS-1, October 1997.

[67] U. S. Bureau of the Census, *1992 Truck Inventory and Use Survey*, May 1995.

Average Value of Time per Vehicle. The travel time values by vehicle class are weighted by using

$$AVOT = \sum_{pc} \left(S_{pc} \times \sum_{vc} df_{vt} \times VOT_{vt} \right) \qquad [26]$$

where $AVOT$ = average value of time for all vehicles, S_{pc} = share of vehicles in each of the three primary categories, df_{vt} = distribution factor for each elemental vehicle class, and VOT_{vt} = value of time for each of the seven vehicle types.

Train Passenger Time

Data on the income distribution of passengers was provided by the LIRR for the three income items in Table 30. The data are assumed to be recent, and no adjustment was made for inflation. Because the split above and below $75,000 does not add to 100%, it is assumed that the data derive from surveys in which some respondents did not report their income; these shares are expanded to represent the total as if the reported shares have no self-selection bias, yielding population shares of about 29% below and 71% above.[69] Median income is also provided, presumably extracted from the same sample of survey respondents reporting their incomes. No distinction is made between household income and personal income, but it is assumed here that most respondents are primary breadwinners, making the distinction of less importance.

Table 30. Valuation of train passenger time

% passenger income < $75,000		25%
% passenger income > $75,000		60%
unreported		15%
median income	$	105,300
average income per household or individual in ($ per year)	$	116,643
hours worked per year		1880
wage rate	$	62
usability/comfort factor		60%
opportunity cost per hour of passenger time	$	25

From these data, a rough estimate of the distribution of income for LIRR passengers can be constructed, from which average income can be derived. The constructed distribution is shown in Figure 31. The implied average income is above the median, showing that the distribution is slightly skewed (unsymmetrical) by the greater spread among higher incomes relative to lower. The LIRR average is well above the average for the population as a whole.

---

[68] U. S. Department of Transportation, Federal Highway Administration, Highway Performance Monitoring System Analytical Process *Technical Manual*, Version 2.1, December 1987, Table IV-20.

[69] Historical experience seems to indicate that unreported incomes are more likely to be higher than those reported rather than lower. This, as well as the likelihood that the data are somewhat out-of-date, implies that the estimated average income is slightly below the true level.

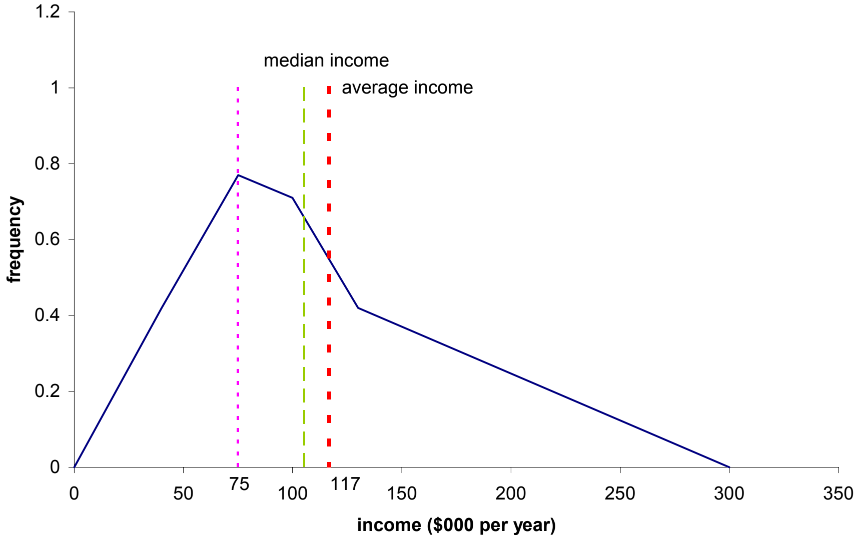


Figure 31. Constructed income distribution of LIRR passengers.

Converting annual income an hourly rate, annual working hours are based on 52 work weeks, 40 hours per week, 10 national holidays, and 3 weeks of vacation per year. The usability factor assumes that, for most passengers, the comfort level is satisfactory and the time can used productively (allowing for wait time, on-board distractions, and boarding and alighting time.

Emergency Vehicle Time

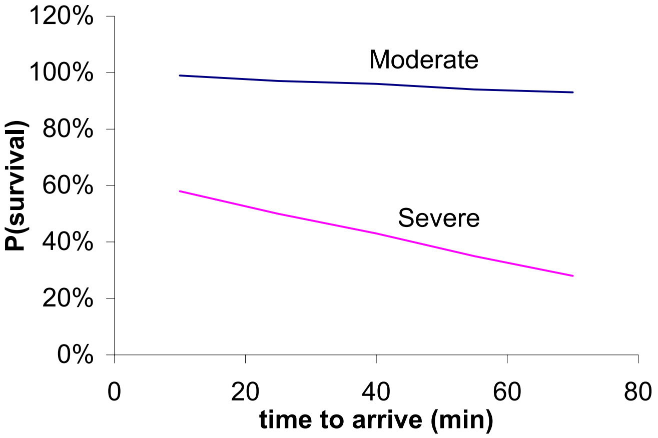
Emergency vehicles include police, fire and rescue, and ambulance services. Estimating a value of time for such activities is clearly very subjective, and the willingness-to-pay concept must be based on society's demand rather than the individual traveler. Deterrence of crime, reducing damage from fire, and saving lives have values that can be monetized, but the impact of any given emergency action is highly variable and is rarely known even after the fact.

Ambulance services are perhaps the most amenable to valuation. Hospital emergency data show that survival rates are directly related to the time between the trauma occurrence and arrival at the emergency room.[70] The data shown in Figure 32 are for severe and moderate injuries in San Antonio. Especially for severe trauma, they show a clear relationship between elapsed time and the probability of survival of about -0.5 percentage points for each minute of time from occurrence to hospital arrival.

At a value of life of $3 million, and assuming that survival generally mean recovery, the value of emergency vehicle time is $15,000 per minute or $900,000 per hour.

---

[70] See Lee (October 2000).



source: San Antonio Trauma Consortium

Figure 32. Relationship between survival and hospital arrival time.

Appendix E: Accident Frequency/Severity Models

Estimation of safety benefits from reduced crashes inevitably must depends on statistical models that extract systematic relationships, between treatments and accidents, from data that contain very few accidents relative to the number of possible occasions, or "trials" in probabilistic terms.

Accident Frequency Modeling

Little or no theory is offered in support of models of collisions between trains and motor vehicles. Most of the models have a form something like

$$A = \alpha T^{\beta} V^{\gamma} P \qquad [27]$$

where A = accidents (or simply a hazard index), T = trains per day or nightly trains, V = vehicles per day, α, β, and γ are model specific parameters, and P = protection factor offered by whatever devices are applied. Early models were simple, later models both more complex and more obscure in their rationale. The DOT model, for example, uses both a TV multiplicative factor as well as another factor with just T. The train measure is typically through trains only, either daily, nightly, or both combined.

For purposes of estimating impact, two strategies might be followed:

(1) Estimate the accident frequency for some set of conditions, and judge the effect of the treatment on the basic frequency, emphasizing the order of magnitude of the estimated frequency as a control of reasonableness. This assumes that the expected rate can be estimated accurately enough.

(2) Derive parameters from the models that measure the differential impact of the treatment on the frequency rate, paying less attention to the absolute magnitude of the collision frequency.

In practice, the first must be used because the models lack the variables that would allow for estimating the impact of changes in relevant characteristics of the crossing controls and warnings. It is clear that reducing gate violations and other risky behavior (e.g., attempts to beat the train to the crossing) can reduce collisions, but the intervening variable of driver behavior has not been observed or measured systematically enough to calibrate any models.

Crossing-Specific Risk Factors

Most highway accidents are the result of a combination of risk factors that include driver performance, weather, and geometrics. Curves, sight lines, pavement surface, and super elevation (for example) can create situations where drivers are more likely to make mistakes than at other locations, and these may be exacerbated by weather and darkness. The probability of an accident is far from constant for each mile of road.

Suitable geometrics for grade crossings have been studied and standardized, however, such that inherently risky geometrics have been much reduced.[71] At gated crossings, the only explanatory risk factor seems to be the decision of the driver to beat the gates or go around them. Site-specific factors, to the extent they differ between crossings and are not included in the models, do not seem to be important. What causes vehicles to run through lowered gates and hit trains is largely unknown (asleep? suicide? didn't "see" the crossing?).[72] Hence the focus in this report on treatments that reduce risky behavior as a means for reducing accidents, but the actual relationship between behavior and accidents is unknown.

Risky Behavior

Most recent studies of grade crossing treatments attempt to measure the effectiveness of the treatment by observing incidents of "risky behavior." What constitutes risky behavior varies with the context: gate violations, pedestrians crossing within 20 seconds in front of a train, motorists crossing after the flashing lights have started but before the gates have come down, or starting up before the gates are fully raised. For practical purposes, these can be reduced to two types for vehicles: continuing through the crossing after the flashing lights have started but before the gates are horizontal (FLV, Flashing Light Violations), and driving around the gates (EV, Enforceable Violation).[73] An observation frequently made is that a large share of collisions are the result of gate violations.

Because the ICS features aimed at safety seek to reduce risky behavior, existing models do not directly incorporate this relationship. Ideally, the relationship would be of the form,

$$A = R \times C_R + O \quad \textbf{[28]}$$

where A = accidents per year, R = risky actions per year, C_R = likelihood of collision given the risky action, and O = all other causes of collisions.

Reduce Gate Violation

Some drivers become impatient when the gates are down and believe that they can drive around the gates before a train comes along.[74] This belief is reinforced by excess gate down time, i.e., gates closed when a train is not imminent. With some probability, a collision occurs between a vehicle and a train. A model can be constructed for estimating the expected reduction in collisions from having gates closed only 30 seconds before train arrival, from posting VMS information, and from leaving the gates open while a train is in the station is shown, but none of the relevant parameters or intermediate variables are readily observable or have been the subject of studies. Thus the approach of using gate violations to predict reductions in collisions was abandoned in favor of the effectiveness rate method (see “Effectiveness Rates” on page 24).

---

[71] AASHTO (2001); FHWA MUTCD (2001); FRA (1986)

[72] For example, DeMarco and Daniel, "Two Elderly Women Killed by Train in North Andover," (2002).

[73] Carlson and Fitzpatrick (2000) group violations into 3 types: flashing lights, legally enforced, and after gates open. The last of these is dropped as insignificant.

[74] FRA Highway-Rail Grade Crossing Accident/Incident Reports show three accidents at NHP since 1979 due to motor vehicles evading the gates

Incremental Treatment Impact

Due to the endogeneity problem, it is effectively impossible to measure the incremental impact of changing the treatment, e.g., adding 2-quadrant gates where previously there were only flashing lights, from cross-sectional data.[75] The models seek to “prioritize” expenditures on the locations where additional treatment (devices, signs, etc.) will generate the most benefit relative to cost (or perhaps only benefit), but the statistical separation of the impact of the treatment from the statistical association of treatment with accidents is weak.

Moreover, if treatments are deployed simply on the basis of accident frequency, the results will be “disappointing,” due to what is referred to as regression-to-the-mean. If events occur randomly, there will be some variation about the mean, or expected average, just like a string of heads or tails. If grade crossings with high accident rates are given priority for safety devices, the accident rates will probably fall, but the rates will also fall if no treatment is applied, as the actual occurrences regress toward the average: above-average rates will tend to fall and below-average rates will tend to rise.

If accidents are not random, then the problem is to identify the cause of any systematic variation. The primary cause is the confluence of motor vehicles and trains; each must be present, and the more of each the more the possibility for collision. This is referred to as exposure. Exposure can be refined by percent trucks and train speed. Beyond exposure are conditions such as surface type, visual obstructions, angle of crossing, and nearby traffic signals. The rest is endogenous, such as pavement markings, warning signs, and active devices.

DOT Model

Nevertheless, each model was constructed by creating a binary accident indicator variable, describing the accident history of each grade crossing (e.g. 0 = no accidents occurred; 1 = at least one accident occurred). This indicator variable was then treated as the dependent variable in a logistic regression model ([29]) which used the characteristics of the grade crossing as the explanatory variables.

$$P(Y_i) = \frac{e^{\phi_i}}{(1 + e^{\phi_i})} \qquad [29]$$

$$\phi_i = \varepsilon + \sum_{k=0}^{n} \beta_k \cdot X_k \qquad [30]$$

---

[75] A few studies use longitudinal data, e.g., before-and-after time series where the treatment was upgraded at the same crossing. Such data allow accident rates to be estimated without the treatment and compared to actual rates after the treatment is applied.

where

$P(Y_i)$ = the probability of an accident occurring at crossing i

ε = independently and identically distributed (IID) Gumbel error term

β_k = parameters of independent variables

X_k = independent variables describing the crossing characteristics

An iterative selection process was used to determine exactly which independent variables were statistically significant in terms of predicting accident probabilities, and therefore should be included in the model. After the logistic regression model was calibrated, it was modified to estimate accident frequencies (accidents/year). The final model is described in the main text ("DOT Model" on page 21).

Canadian Model

This collision prediction model was developed using highway-rail grade crossing data from all over Canada. Since collisions are rare, discrete events, it is assumed that they are distributed according to a Poisson probability distribution.

$$P(a_i) = \frac{e^{-\lambda_i} \cdot \lambda_i^{a_i}}{a_i} \quad [31]$$

$$\lambda_i = e^{\sum \beta_k \cdot X_k} \quad [32]$$

Where

a_i = the expected number of accidents at crossing i

$P(a_i)$ = the probability of a collisions at crossing i

λ_i = the Poisson parameter as defined in equation [32]

β_k = parameters of independent variables

X_i = independent variables

The Poisson distribution requires the expected number of collisions to be equal to the variance. If the variance is greater than the expected value, then the data is said to be over-dispersed. Similarly, when the variance is less than the expected value, the data is under-dispersed.

Like the DOT model, this model was also formulated by separating the data into different sets based on the type of warning device present at the crossing and by developing independent models for each warning device type. The equation developed for the warning device of automatic gates is shown in equation [33] on page 83.

$$a = e^{-8.7407} \times (Exposure)^{0.258} \times e^{-0.1428 \times tracks} \quad [33]$$

The data used to generate the model for automatic gates was not over or under-dispersed; therefore, the Poisson model is a valid approximation for this data set. This was not the case for the other models developed for crossing with different types of warning devices (signs, signs and flashing lights) as the data was significantly under-dispersed. However, this division of the data into separate groups still does not correct the endogenous relationship between the collision probability and the warning device.

Nevertheless, for the New Hyde Park highway-rail grade crossing, this model predicts 0.0062 accidents per year, which is roughly one accident every 161 years.

Negative Binomial Model

This model was developed using highway grade crossing data from a sample of six states (California, Montana, Texas, Illinois, Georgia, and New York) over a 2 year period (1997 and 1998).[76] This data set cannot be modeled with a Poisson distribution because the sample variance is greater that than expected value of the sample. Since the data is over-dispersed, the negative binomial distribution can be used. The reason being that this distribution relaxes the Poisson constraint of expected value equals variance through the use of a Gamma-distributed error term (ξ) added into the Poisson parameter.

$$\log(\lambda_i) = \xi + \sum_{k=0}^{n} \beta_k \cdot X_k \quad [34]$$

This model also handles the endogenous relationship between the probability of a collision and the type of warning device through the use of Instrument Variables. For each crossing the warning device classes are treated as discrete, binary variables (i.e. automatic gates: yes = 1, no = 2). These variables will serve as the dependent variable in a logit regression model where the explanatory variables are the crossing characteristics (i.e. AADT, number of tracks, number of highway lanes, etc.). The logit model takes the form

$$P(WD_i) = \frac{e^{Z_i}}{1 + e^{Z_i}} \quad [35]$$

$$Z_i = \varepsilon + \sum_{k=0}^{n} \alpha_k \cdot X_k \quad [36]$$

---

[76] The negative binomial model developed by Austin and Carson (2000) as an alternative to the DOT model gives an expected accident rate at NHP of 0.201 collisions per year, using the same database but including more recent data. Hauer and Persaud (1989) also show the applicability of the negative binomial, but do not construct an empirical model.

where

$P(WD_i)$ = the probability of a particular warning device at crossing i

ε = independently and identically distributed (IID) Gumbel error term

α_k = parameters of independent variables

X_i = independent variables

Independent logit models had to be estimated for each type of warning device. For every grade crossing in the data set, a probability of occurrence was calculated for each type of warning device using these models. These probabilities indicate how likely it is for a particular type of warning device to be present at a given grade crossing; furthermore, these probabilities can then be used as explanatory variables in the negative binomial regression instead of the endogenous warning device indicator variables. The negative binomial model consists of the following independent variables and their associated coefficients.

Table 31. Negative Binomial Accident Prediction Model Results

Independent Variables	Coefficients
Constant	-6.719
Number of nightly through trains	0.039
Maximum timetable speed	0.021
Number of main tracks	0.484
Number of traffic lanes	0.170
AADT in both directions	3.59E-05
Highway paved or gravel	0.295
Surface, sectional	0.260
Surface, full wood plank	0.312
Pavement markings: stop line	0.747
Probability of a stop sign	19.615
Probability of a gate	-2.974
Probability of flashing lights	1.075
Probability of a highway traffic signal	-114.447
Probability of bells	0.649

For the New Hyde Park highway-rail grade crossing the assumption is made that the data is not overdispersed which implies the Poisson distribution is an appropriate model to use. This assumption is reasonable because the average number of accidents per year is roughly 0.28 (8 accidents in 28 years), and the sample variance is also 0.28. Since this assumption holds we can utilize the Poisson model in which lambda (λ) is the expected number of accidents per year. Unfortunately the coefficients for the Poisson model were not provided in the reference; however, the assumption can be made that the coefficients do not vary drastically between the Poisson and the negative binomial models. The reason being that the Gamma distributed error term incorporated into the negative binomial model should compensate for the possibly biased coefficients in the Poisson model. Finally, the estimated number of accidents per year is 0.0017, which is roughly one accident every 589 years.

The state where a particular grade crossing is located is a independent variable in the warning device logit models, and surprisingly the value of this variable heavily influences the number of accidents predicted for the grade crossing. For instance if the New Hyde Park grade crossing was located in Texas (or for a grade crossing in Texas with identical characteristics), then the model would predict 0.345 accidents per year, which is one accident every three years. Shown below are the accident estimates obtained by modifying the state variable.

Table 32. Effect of State Variable on Accident Rates

State	Accidents / Year	Years / Accident
Montana	0	∞
California	0.0204	49
Texas	0.3454	3
Illinois	0.0927	11
Georgia	0.2906	3
New York	0.0017	589

One way to handle the heavy influence of the location of the grade crossing is assume it is likely that there are grade crossings in each of these other states having exactly the same characteristics as the New Hyde Park crossing. This allows an average to be taken over all the states accidents rates, resulting in 0.1480 accidents per year at New Hyde Park (1 accident every 7 years). This estimate of the accident rate seems much more in line with recent history and with the other accident prediction models.

Comparison of Risk Prediction Models

In conclusion, the Canadian and US DOT accident prediction models (for automatic gates) have very similar closed forms even though they were generated through different methods and predict very different accident rates. Furthermore, both models create three independent sub-models based on the type of warning device in use at a particular crossing. The final point of interest is that the Canadian model uses a subset of the explanatory variables used in the US DOT Model. The explanatory variables of daily through trains and highway lanes were not find statistically significant in the Canadian model.

The negative binomial model was developed using a similar method as the Canadian model (Poisson model); however, it has significantly more explanatory variables in it final formulation. This model is also the only one to correct the endogenous relationship between the warning device class and the probability of an accident. The main weakness of this model is the high state to state variability and the comparatively

Table 33. Comparison of DOT and Canadian Accident Models

Factor	DOT Formula	Canadian Formula
Constant	0.0005745	0.0001599
Exposure	$\left(\frac{Exposure + 0.2}{0.2}\right)^{0.2942}$	$(Exposure)^{0.258}$
Daily through trains	$\left(\frac{ThruTrains + 0.2}{0.2}\right)^{0.1781}$	1
Main tracks	$e^{0.1512 \cdot tracks}$	$e^{-0.1428 \cdot tracks}$
Highway lanes	$e^{0.142 \cdot (lanes - 1)}$	1
Effect	0.4921	1

small amount of data used for this study (6 out of 50 states and 2 out of 28 years); however, the attempted correction for the state to state variability yielded more plausible results.

In conclusion, the goal of this analysis is to determine a valid accident rate estimate to be used as the baseline in evaluating the benefits of different safety measures. The US DOT model seems to be the most accurate predictor based on the recorded accident history in the past 28 years (5 rail-car accidents and 2 rail-pedestrian accidents). The US DOT prediction without the adjustment for accident history is the closest predictor to the historical average, and is used as the baseline accident rate through this analysis.

Table 34. Results of Accident Prediction Models

Model	Accident / Year	Years / Accident
DOT (Without accident history)	0.2170	5
DOT (No accidents in recent history)	0.0628	16
DOT (1 accident in recent history)	0.1327	8
Canadian	0.0062	161
Negative Binomial (NY state only)	0.0017	589
Negative Binomial (averaged of all states)	0.1480	7
Historical Average	0.1790	4

Accident Severity Model

In addition to the accident prediction model, the US DOT has also defined a model to estimate percentage of fatal accidents, injury accidents, and property damage only accidents.

There are four classifications of accident severities:

- Fatal - at least one fatality
- Casualty - at least one fatality or injury
- Injury - at least one injury, but no fatalities
- Property Damage Only - no injuries or fatalities

The probability of a fatal accident given an accident is estimated by the following formula:

$$P(FA|A) = \frac{1}{1 + (KF \cdot MS \cdot TT \cdot TS \cdot UR)}$$

where

Factor	Factor Description	DOT Formula (Flashing Lights and Gates)
KF	constant	$KF = 440.9$
MS	Factor for the maximum timetable train speed	$MS = MaxSpeed^{-0.9981}$
TT	Through trains per day factor	$TT = (ThruTrains + 1)^{-0.0872}$
TS	Switch Trains Per Day Factor	$TS = (SwitchTrains + 1)^{0.0872}$
UR	Factor for urban (*ur* = 1)or rural (*ur* = 0) crossing	$UR = e^{0.3571 \cdot ur}$

The probability of a casualty accident given an accident is estimated by the following formula:

$$P(CA|A) = \frac{1}{1 + (KC \cdot MS \cdot TK \cdot UR)}$$

where

Factor	Factor Description	DOT Formula (Flashing Lights and Gates)
KC	constant	$KC = 4.481$
MS	Factor for the maximum timetable train speed	$MS = MaxSpeed^{-0.343}$
TK	Factor for the number of tracks	$TK = e^{0.1153 \cdot tracks}$
UR	Factor for urban (*ur* = 1)or rural (*ur* = 0) crossing	$UR = e^{0.296 \cdot ur}$

Injury and property damage accidents are defined in terms of the casualty and fatal accidents. The probability of an injury accident is the probability of a casualty accident minus the probability of a fatality accident.

$$P(IA|A) = P(CA|A) - P(FA|A)$$

Similarly, the probability of a property damage only accident can be computed.

$$P(PDO|A) = 100 - P(FA|A) - P(IA|A)$$

Appendix F: Variable Message Sign Effectiveness

VMS Effectiveness

VMS signs reduced risky behavior at a LRT grade crossing in suburban Baltimore.[77] No accidents occurred before the installation between 1992-1996, but 100 gate arms were broken. The problem is described as “second train coming” (STC) but is partly a transient gate opening problem (opening less than 10 seconds before closing again).

Table 35. Impacts of Maryland STC Warning Sign.

	Before	1st After Period	2nd After Period	Percentage Change	
	(1)	(2)	(3)	(2) vs. (1)	(3) vs. (1)
Total number of STC incidents	320	363	348		
Pedestrians crossing Timonium Road in front of downed gates	0.625 (2)	0.275 (1)	0.000 (0)	-56%	-100%
Drivers crossed gate line, but stopped after realizing that a second train was coming, and drove backward behind the line to avoid the gate crashing on their vehicles	1.250 (4)	1.653 (6)	2.299 (8)	+32%	+84%
Vehicle stopped in front of gate while train was crossing	0.313 (1)	0.0 (0)	0.000 (0)	-100%	-100%
Drivers started to move forward after the first LR vehicle crossed Timonium Road, and the gates were down, but stopped after realizing that a second train was coming	6.563 (21)	2.755 (10)	0.862 (3)	-58%	-87%
Vehicles crossed the tracks *after* the first LR vehicle cleared Timonium Road while the gates were ascending but have not reached the full upward vertical position and *before* the gates descended again for the second coming LR vehicle	16.563 (53)	13.499 (49)	11.207 (39)	-19%	-32%
Total Observations**	25.938 (83)	20.386 (74)	16.667 (58)	-21%	-36%

Note: all observations are normalized per 100 STC incidents during each period. Improvement shown is for the normalized observations. The actual number of observations is shown in parentheses.
** This total includes patterns of behavior not listed above; therefore, this total is greater than the sum of the categories.

Track circuits are set to achieve 25 seconds CWT at 50 mph. Risky behaviors were reduced, as shown in Table 35, but there are no data on traffic volumes.

Defining “risky behavior” to include drivers starting up after the gates started to open but before the lights stopped flashing expands the scope of risky to include fairly normal behavior; it is only risky if a second train is coming and the gates are about to come down again. Gate violations were zero in the base case, probably due to the fairly consistent CWT.

---

[77] Maryland Mass Transit Administration and Sabra, Wang & Associates (2001).

Appendix G: Constant Warning Time Technology

This appendix describes three types of systems that can be used to provide constant warning time at a highway-rail grade crossing:

- Grade Crossing Predictors
- Communications Based Train Control
- Custom Designed Systems

The following sections provide an overview of each system. A brief description will be provided along with some costs, benefits, and limitations of each system.

Grade Crossing Predictors

A grade crossing predictor (GCP) builds on the traditional fixed block track circuit infrastructure to detect the presence, direction and motion of a train within the approach circuit of a grade crossing. In a fixed block track circuit, a low voltage current is applied to one of the running rails at one end of the block and is returned via the other running rail. A relay (or solid-state controller) at the other end of the block detects the voltage and instructs the grade crossing gates to remain open. When the first set of train wheels enters the block, the circuit is broken (i.e. the current never makes it to the relay) thereby causing the crossing gates to descend. This is an example of a “fail-safe” or “vital” system, since any break in the circuit will cause the gates to descend.

A grade crossing predictor builds on this technology by also acting as a type of track circuit. Signals are injected into the rails, and the track impedance is monitored to determine train speed and its distance from the grade crossing. Once the circuit has been shunted, train motion is detected through measurement of the changing impedance of the track circuit due to train movement. The grade crossing equipment remains activated as long as decreasing impedance is measured, and is deactivated when the impedance becomes constant for a specific period of time (indicating the train has stopped) or when an increasing impedance is measured (indicating the train has passed the crossing and is moving away).

CWT equipment consists of a transmitter, receiver, processing equipment and special provisions (i.e. island track circuit) for detecting the train in the grade crossing. In addition, shunts are employed on both approaches to the grade crossing that define the boundaries of the circuit. The boundaries of the island circuit are usually established by tapping electrically into the rails on both sides of the grade crossing.

This type of system is accurate to approximately within 5% of the velocity of the train. The cost of implementing this technology on a crossing is on the order of $200,000. This system can be utilized for a single crossing or for multiple nearby crossings. This is also the predominant technology for constant warning time in the freight railroad industry.

Unfortunately this type of system cannot be used in an electrified railroad system like the Long Island Railroad, the reason being that electric traction systems use the same running rails for the traction return current. The current is permitted to pass over the insulated joints on its way back to the substation. The additional current on the running rails, however, causes interference with the grade crossing predictor. The grade crossing predictor may detect changes in the track circuit impedance due to the traction return current, and this would cause the crossing warning device to be activated when in fact no train was present in the block.[78]

At the time of completion of this report, GE Transportation Systems was in the process of testing a new version of their grade crossing predictor on class I railroads. This new product has an increased level of noise immunity, and depending on the characteristics of the particular grade crossing, may be suitable in an electrified environment. More detailed testing and analysis of the New Hyde Park grade crossing would be needed to determine if this is a viable solution.[79]

Communications Based Train Control (CBTC)

Communications Based Train Control (CBTC) systems are another type of system capable of providing constant warning time at a highway-rail grade crossing. CBTC systems can be further subdivided into two main categories: Incremental Train Control Systems (ITCS) and Advanced Automatic Train Control Systems (AATCS). The main difference between these two types of CBTC is the incremental system builds upon the existing fixed block technology (signals, switches, etc.) whereas the advanced system does not. The advanced system instead implements a moving block design where a communications system (rather than track circuitry) is used to monitor in real-time the location, speed, and direction of the all trains.

An example of an incremental system is the ELSIE CBTC system developed by Alstom Transport. Train detection at a grade crossing under the ELSIE technology is achieved through a combination of track circuits and transponders (or beacon system) installed along the railroad right-of-way.[80] Track circuits are used for train detection at the grade crossing approach circuit and at the grade crossing island circuit.

The Alstom CBTC technology leverages a distributed wayside control architecture, where the intelligence for maintaining safe train separation is divided into a series of zones, each under the supervision of a zone controller. A track circuit is installed at the entrance to each zone for train detection. The track circuit technology is required in conjunction with the CBTC system for two reasons. First, the ELSIE technology is an overlay system and thus is still dependent on the track circuit technology for vital functions such as train detection. In the event of a failure in the CBTC system, the track circuit technology will still be operational for train detection. Second, not all trains may be equipped with CBTC technology, or the technology may not be operational, thereby requiring the redundancy of the track circuitry.

---

[78] American Railway Engineering & Maintenance of Way Association (2003)

[79] Phone conversation with Gary Young of GE Transportation Systems on February 23, 2004.

[80] See Figure 2 on page 4.

When a CBTC equipped train enters a grade crossing zone, it is first detected by the approach circuit for the grade crossing. The train then encounters a series of encoded beacon transponders installed in the railroad right-of-way. These beacons are passive devices that are encoded with location information. An active beacon reader mounted to the bottom of the train interrogates the track beacons and transmits the location information to the locomotive computer. When the train is between beacons, an axle driven tachometer generator is used to extrapolate train location. The beacons are located at intervals such that any accumulated distance measurement errors are minimized.

Incremental systems are extremely reliable since they build on the existing block control technology that is widely accepted by the railroad industry. Train speed and position information is highly reliable, and it can be used to provide constant warning time with typical variances of 5 to 10 seconds. Incremental systems are currently used on a daily basis by Norfolk Southern and Amtrak in various corridors.[81] The components used in these implementations are not transferable to the LIRR system, however, because of the electrified territory issue previously identified.

Incremental versions of CBTC are currently in use in the U.S. An example of an “advanced” system is the advanced automatic train control system produced by GE Transportation Systems. GPS technology is used to provide continuous speed control, train tracking, signal-less operation, and reduced train spacing. This type of system is highly reliable; every half second, train information is transmitted to the wayside controller, which relays the information to each train.

According to the FTA, the Bay Area Rapid Transit (BART) is considering using CBTC as an alternative to a $3 billion dollar investment in the major infrastructure required for system expansion. Furthermore, the FTA has a goal of demonstrating this technology at two or more locations in the next five years, with candidates including New York and Philadelphia. The FTA also recognizes the need for national CBTC standards, and is working with industry partners to establish these standards once the technology is more widely deployed.[82]

Custom Solutions

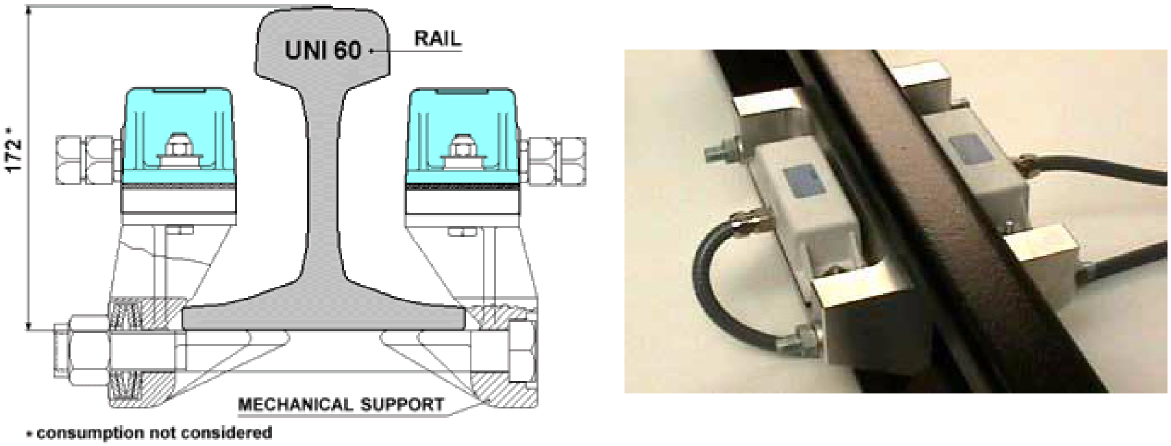
Three types of custom-designed solutions are available, which link multiple technologies together in order to create a system capable of providing constant warning time at a grade crossing in electrified territory. These systems are largely experimental or under development, and are not yet ready for application to a high-speed electrified system.

Axle Counter Systems. Axle counter systems (ACS) are stand-alone block control systems used extensively throughout Europe. They are an alternative to the track circuit methodology predominantly used in the US to monitor the presence of a train in a block. Typically these systems consist of two fail-safe electronic wheel detectors (shown in Figure 33) placed at each end of the block section. An electronic wheel detector consists of a transmitter unit and a receiver unit encased and bolted to the running rails of the track. The transmitter and receiver create a magnetic field from one side of the rail to the other. When a train enters the block, its wheels pass through the magnetic field thereby interrupting the field. This interruption at the beginning of block triggers the crossing controller to activate the crossing warning device. Similarly, when the last wheel on the train leaves the block, the controller deactivates the warning device, as shown in Figure 34.

---

[81] https://www.getransportation.com/general/apps/global_signaling/Systems/Detail/itcs.asp

[82] http://www.fta.dot.gov/11325_11352_ENG_HTML.htm


UNI 60
RAIL
172*
MECHANICAL SUPPORT
* consumption not considered

Source: https://www.getransportation.com/general/apps/global_signaling/Products/Detail/drt.asp

Figure 33. Electronic Wheel Detector

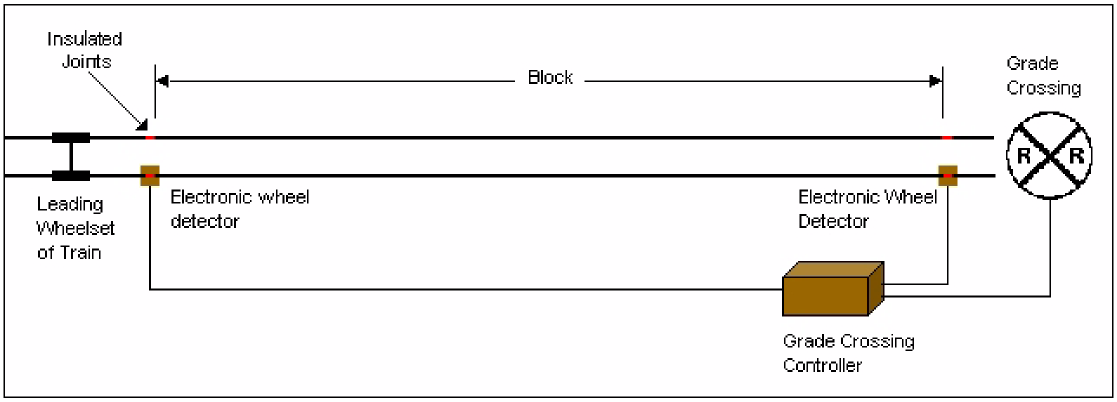

Insulated Joints
Block
Grade Crossing
R
R
Leading Wheelset of Train
Electronic wheel detector
Electronic Wheel Detector
Grade Crossing Controller

Figure 34. Block Control Using Axle Counter System

This same technology could also be utilized to provide constant warning time at a highway-rail grade crossing. A series of electronic wheel detectors would be equally spaced throughout a block, much like the beacons in the Alstom system. The crossing controller would use the readings from the first two wheel detectors to determine the speed of an approaching train. This would provide the initial estimate for the train's estimated arrival time at the crossing. Subsequent wheel detectors would be used to monitor and adjust the original estimate. This would account for trains that may be accelerating or decelerating within the block. Each time a train activated a wheel detector, the crossing controller would compute a revised estimate of the train's estimated arrival time, which would allow for constant warning time to be provided at the crossing. The concept is illustrated in Figure 35.

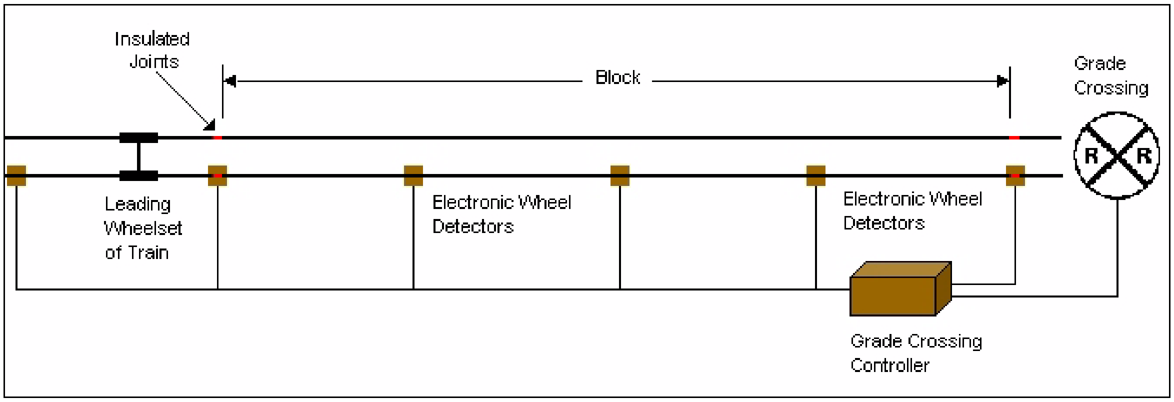

Insulated Joints
Block
Grade Crossing
R
R
Leading Wheelset of Train
Electronic Wheel Detectors
Electronic Wheel Detectors
Grade Crossing Controller

Figure 35. Constant Warning Time Using Axle Counter System

Unlike the other custom solutions, axle counter systems are vital, proven systems for block control, and are currently used, for example, at over 1,400 sites in Italy. They have been approved for block control by the European Committee for Electrotechnical Standardization (Cenelec), a technical organization established under Belgian law responsible for standardizing electronic systems used through Europe.[83]

While axle counter systems are unproven for providing constant warning time at a grade crossing, work is currently being done to extend these systems to cover such an application. GE Transportation Systems (European Division) is currently working on a project to use an axle counter system to provide constant warning time at a highway-rail grade crossing. The approximate cost of implementing such a system for a single grade crossing is on the order of $500,000.

Wayside Magnetometer. Another type of custom-developed system is very similar in design to the axle counter system discussed in the previous section, except that wayside magnetometers are used in place of electronic wheel detectors. Magnetometer sensors were first commercialized in the 1960s as an alternative technology to inductive loops for detection of highway vehicles. Functionally, wayside magnetometers are very similar to electronic wheel detectors as both devices detect changes in a magnetic field caused by the presence of a train. The main difference is the magnetic field being observed by each device. Unlike electronic wheel detectors, which create a small magnetic field, wayside magnetometers detect changes in the earth's ambient magnetic field. These changes result from the presence of ferrous metals, as from a train, within the detection area of the magnetometer.

---

[83] Lionetti, G. "GE Transportation Systems and its Suppliers" 26 September 2002. http://www.unife.org/innotrans2002/docs/seminar3/GETS_2.pdf.

In train detection applications, a series of variable sensitivity magnetometers are installed along the wayside approximately six feet from the rail. The sensitivity of the sensors can be optimized to prevent detection of unwanted vehicles. The data collected from each sensor is transmitted to a wayside logic center for calculating train speed and location with respect to the crossing. Once the train speed and relative location have been derived, the constant warning time can easily be calculated.

One of the salient points of this technology is that it is not affected by potential rail contaminants including sand, salt, rust/corrosion, lightning, and precipitation. However, the accuracy of this system is not well established. Its approximately costs are roughly equivalent to that of the axle counter system, which includes the vault, logic center, sensor array, island detection circuit, power supplies and batteries. This type of technology is currently used by approximately 10 locations in the United States.

Doppler Radar System. A custom system called Advance Warning to Avoid Train Delays (AWARD) was developed and implemented at a grade crossing in San Antonio under the Metropolitan Model Deployment Initiative (MMDI). The goal of this system was to detect the presence and speed of an approaching train, and alert users of the nearby highways (traveling public and emergency service providers) to the impending delay at the crossing. This information would allow highway users to utilize a alternate route in the event of a train blocking their primary route. Because train speeds were often slow, the typical delays at this crossing were on the order of 3 to 7 minutes with maximums around 10 minutes.[84]

This system is fairly similar in concept to the axle counter system previously discussed. It uses acoustic vehicle detectors and Doppler radar to detect the presence, speed, length, and acceleration rate of an approaching train. Acoustic vehicle detectors would be alerted to the presence of a approaching train by its acoustic emission. Doppler radar units detect the train speed by emitting radio waves which are reflected by an approaching train. The speed is determined from the shift in frequency of the reflected radio wave. All of this information was used to compute the expected time of arrival at the highway-rail grade crossing and alert travelers of the delay.

While this system does not meet the rigorous safety standards required for constant warning time systems, it does provide a proof of concept for the general methodology. Also the cost numbers are fairly relevant since this custom system has a number of elements in common with the other custom systems discussed. The cost of capital costs for this system were $350K and the annual operational costs were $33K.

---

[84] Carter, Luttrell, and Hicks (2000)

Appendix H: Vehicle Detection Technology

Automatic detection of the presence of a vehicle is widely used in highway operations, and can be accomplished by a variety of devices and systems. For use in the ICS, the purpose of automatic vehicle detection is to inform the train of an obstacle on the tracks in the grade crossing, before the obstacle is visible to the train operator, so that appropriate action can be taken.

Inductive Loop Detectors

The data supplied by inductive loop detectors are vehicle passage, presence, count, and occupancy. The principal components of an inductive loop detector are one or more turns of insulated wired buried in a shallow cutout in the roadway, a lead-in cable which runs from a roadside pull box to the controller, and an electronics unit located in the controller cabinet. The wire loop is excited with a signal ranging in frequency from 10 kHz to 200 kHz and functions as an inductive element in conjunction with the electronics unit. When a vehicle stops on or passes over the loop, its inductance is decreased. The decreased inductance increases the oscillation frequency and causes the electronics unit to send a pulse to the controller, indicating the presence or passage of a vehicle.

The introduction of digital signal processors has allowed more reliable, accurate, and precise measurement of the change in oscillation frequency or period associated with the loop output that is produced when a vehicle passes over the loop. The improved capability of the detector, in turn, has increased the accuracy of the presence, count, and occupancy measurements. The data processed in the electronics unit can be either the changes in frequency or period that are measured, or the ratio of the change to its initial value.

The output of most inductive loop detectors is a simple relay or semiconductor closure, signifying the presence or absence of a vehicle. In advanced detector processing systems, some vehicle classification and fault detection can be performed by digitizing the detector output and feeding it to a microprocessor containing embedded signal processing algorithms. These match the detector output to stored signatures for specific types of vehicle types or fault conditions. Digital codes can be output to identify the type of vehicle detected or report detection faults to a central processing unit.

In the past two decades, loop detector technology has become the most widely used and accepted traffic detector technology in America today. The loop detector system, however, may still suffer from poor reliability, primarily from improper connections made in the pull boxes and in the application of sealants over the sawcut. These problems are accentuated when loops are installed in poor pavement or in areas where utilities frequently dig up the roadbed. Reliability can be improved by installing loops using newer procedures and loop wire protective enclosures developed by manufacturers and user agencies. Improved traffic system operation can be obtained by holding daily loop status meetings at which the malfunctioning loop detector locations are identified and repair teams are dispatched. Another disadvantage of loops is their inability to directly measure speed. If speed is required, then a two-loop speed trap is employed or an algorithm involving loop length, average vehicle length, time over the detector, and number of vehicles counted is used with a single loop detector.

Specifications. The National Electrical Manufacturers Association (NEMA) specifies that a detector unit respond to the arrival or departure of a small motorcycle into and out of a 6- x 6-ft. (1.8- x 1.6-m) loop within 125 ms. An automobile call must be initiated or terminated within 50ms. NEMA also states that for certain specific surveillance applications which involve vehicle speeds in excess of 45 mph (72 kph), more precise response times might be required.

Costs. Typical installation costs for this type of system are between $9,000 and $16,000. Operations and yearly maintenance are between $1,000 and $1,600, and the expected lifetime of such a system is only about 5 years.

Microwave Radar

Two types of microwave radar detectors are used in traffic management applications. The first transmits electromagnetic energy at a constant frequency. It measures the speed of vehicles within its field of view using the Doppler principle, where the difference in frequency between the transmitted and received signals is proportional to the vehicle speed. Thus, the detection of a frequency shift denotes the passage of a vehicle. This type of detector cannot detect stopped vehicles and is, therefore, not suitable for applications that require vehicle presence such as at a signal light or stop bar.

The second type of microwave radar detector transmits a sawtooth waveform, also called a frequency-modulated continuous wave (FMCW), which varies the transmitted frequency continuously with time. It permits stationary vehicles to be detected by measuring the range from the detector to the vehicle and also calculates vehicle speed by measuring the time it takes for the vehicle to travel between two internal markers (range bins) that represent known distances from the radar. Vehicle speed is then simply calculated as the distance between the two range bins divided by the time it takes the vehicle to travel that distance. Since this detector can sense stopped vehicles, it is sometimes referred to as a true-presence microwave radar.

Wireless Video

This involves on board locomotive monitoring of grade crossing activity that allows the engineer to view and avoid any potential obstructions at grade crossings. A wide angle (6mm) video camera, video transmitter, and directional antenna installed at the grade crossing transmit live video signals to the locomotive. A specially designed circular polarized receiver antenna installed on the front of the locomotive receives the video signal as the train approaches the grade crossing.

Inside the locomotive cab, a video monitor is installed that displays the entire field of view at the grade crossing. This type of system may also include machine-vision detection for advanced warning of potential obstructions at the grade crossing. The video monitor is only activated when an obstruction is found within the grade cross-

Table 36. Microwave Radio Specifications

Category	Typical Values
Frequency	24 GHz, FMCW non-pulsing radar
Transmitter Power Output Range	1 - 10 mW
Reliability	MTFB > 4 years
Minimum dimension of obstacle	0.5m x 0.5m x 1.0m
Maximum Size of Surveillance Area	20m x 20m
Temperature Range	-40 Celsius to +70 Celsius
Vibration/Shock	1 g
Antenna Rotation Speed	1/second
Beam width	10 degrees
Power Output	1 mW
Price	$4,990

ing detection zone. If no hazard is detected at the grade crossing then the video monitor displays a blank screen.

As an example of this type of system is the Wireless Technology FS2400 Grade Crossing Video System. A typical frequency range of 2.4 to 2.483 GHz and a range of up to 50 miles depending up the system.

Appendix I: Preemption by Emergency Vehicles

Instances in which a highway vehicle can request priority over a train at a grade crossing are rare if not nonexistent. Grade crossings are under the control of the railroad, in the interest of safety. Railroads try to avoid situations that give rise to accident risk or present risk that is hard to control. Vehicle priority or preemption is common in other contexts, however, and some of that experience may be relevant to grade crossing preemption.

Purposes and Methods of Preemption

There are generally two kinds of preemption of traffic control devices: control of the signal by a vehicle, and control of the signal by a railroad. Highway vehicles preempting a traffic signal are usually either transit vehicles (buses, light rail) or emergency vehicles (fire, ambulance). Railroad preemption of a traffic signal is for the purposes of clearing the grade crossing if the traffic signal is close enough (required for 200 feet or less) to potentially cause traffic queues to back up onto the crossing.

(1) Transit Vehicle Preemption. Traffic signal preemption for transit vehicles is usually incorporated with signal priority, in that the transit vehicle may not receive an immediate green but may have the green held longer or started sooner if conditions permit. Relevant conditions depend upon location and traffic, but in congested areas where speeds can be slow the effect of the change in signal timing on traffic in the rest network may be large and adverse. If the transit vehicle is ahead of schedule, then signal preemption produces no benefit for the transit operation.

(2) Emergency Vehicle Preemption. Where a traffic signal is near a fire station or on a street providing access to a hospital, allowing fire trucks and ambulances to preempt the signal creates obvious benefits (including fewer crashes with other vehicles) that override possible negative effects. Events do not occur all that frequently, and network effects are generally limited. Alternative routing is often incorporated into signal preemption for emergency vehicles.[85]

(3) Railroad-to-Traffic Signal Interconnect. Preventing vehicular traffic at a traffic signal from interfering with the rail operations is relevant for crossing safety and for optimization of traffic operations around the grade crossing (see below “Local Traffic Management” on page 36), but is not applicable to the present case of preemption of the grade crossing.

Current Emergency Vehicle Activity in New Hyde Park

The New Hyde Park Fire Department provides fire and ambulance service to the Village of New Hyde Park. In the year 2001 they received 1125 rescue calls. For the purpose of this evaluation each call has been categorized as a response and each response in broken into trips. A response is composed of exactly two trips: one from the fire station to the emergency location, and one from the emergency location to the hospital. Thus in 2001 the New Hyde Park Fire Department would have made 2250 trips.

---

[85] e.g., www.utms.or.jp/english/system/fast.html.

The New Hyde Park Fire Department is located on Jericho Turnpike, just north of the New Hyde Park Road grade crossing. Not every emergency vehicle that is dispatched by the fire department will cross the railroad tracks. To determine the percentage of trips that would need to cross the tracks it was assumed that all areas of the Village of New Hyde Park have the same probability of occurrence of an emergency. A year 2000 census map of the village was used to calculate the land areas on each side of the railroad, as shown in Figure 36. Since the area south of the LIRR tracks is 31% of the total square mileage of the Village of New Hyde Park, that is taken to be the percentage of trips that would have to traverse the grade crossing.

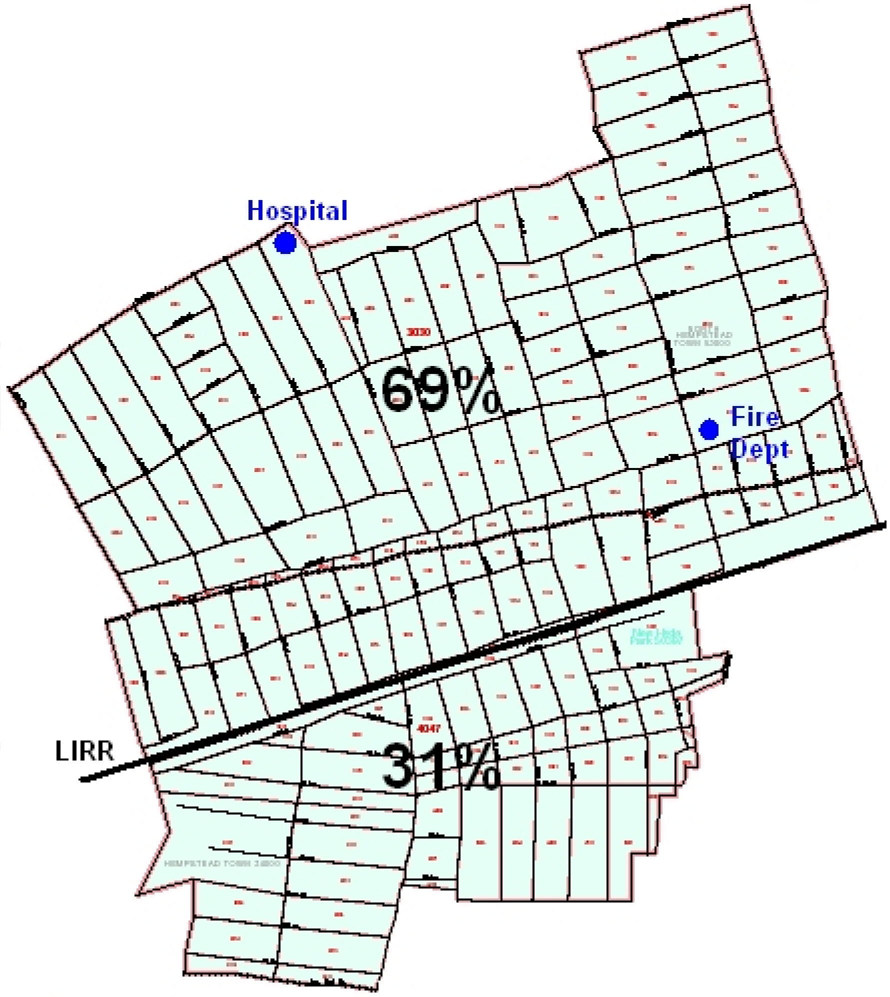


Figure 36. Map of New Hyde Park Village

Not all of the 31% of trips traversing the grade crossing will need preemption. The only emergency responses that require preemption are severe trauma cases where seconds count, and certain fire emergencies. A study done in the United Kingdom estimated the percent of ‘life threatening” calls to emergency responders.[86] The numbers varied by district, ranging from 8% to 47%; an average percentage was judged to be around 20%.

Emergency preemption requests could be refused by the LIRR if a train is too close to the grade crossing to be stopped comfortably, if the warning devices have already been activated at the crossing, or if slowing (or stopping) one train would delay subsequent trains on the line. During peak periods, LIRR trains are scheduled to pass through the crossing at intervals of about 10 minutes in the same direction, which would allow for some delay (e.g., less than 30 seconds) without disrupting schedules. The peak ride times on the Long Island Rail Road are from 6AM-9AM Westbound and 4PM-7PM Eastbound. For these six hours of the day, preemption requests would be less likely to be granted than during offpeak periods. Given the subtleties in real-time negotiation of granting preemption requests, it is estimated that the success rate might be around 50% during permitted hours.

While the rule of not delaying more than one train is simple to state, its implementation is not. The LIRR is responsible for 293 crossings in numerous towns throughout its service area. Allowing emergency preemption at all of them almost certainly would be infeasible, even if all requests were denied while one was pending. A more plausible strategy would be to equip a select few crossings where emergency vehicles are frequently held up and nearby alternative crossings are not available.

---

[86] Meek (2002).

Appendix J: Facilitating Local Traffic With ITS

Due to the absence of traffic signals in the vicinity of the NHP crossing, the potential for ITS applications to move local traffic more efficiently—such as easing movements of traffic not intending to use the crossing but which is nonetheless blocked by crossing queues—seems to be small. A method for estimating the benefits of such improvements if they were suitable, however, has been constructed for this project.

Increase Throughput

One strategy for minimizing the impacts of gate closings on local traffic would be to enhance throughput over the crossing during periods when the gates are open, and seek to move non-crossing traffic when the gates are down. Increasing the volume or effective capacity of New Hyde Park Road as it crosses the tracks might be accomplished by setting signal timing plans to favor crossing-bound traffic for some period of time after a closing, and to favor other traffic when the gates are closed.

The circumstances with improved throughput can be represented analytically by an increase in the highway capacity at the grade crossing and a reduction in the arrival rate (see Table 5 on page 16). Assuming an increase in effective capacity of 5%, matched with a volume reduction of 5%, the delay savings are shown in Table 37. The estimates are obtained by comparing the delay savings for CWT under the two different "base" case scenarios (with and without higher capacity and lower volume)

Table 37. Delay savings from increasing throughput on NHP Road

Local Traffic Management	Total Annual Delay	Total Annual Cost
Base (without ICS)	14,364	$329,077
Increased Throughput	6,294	$144,197
Time Savings	8,070	$184,880

Redirecting traffic using existing traffic signals does not appear feasible, but the capacity of the crossing could be improved by solving the left turn problem at Clinch Avenue (see "Local Traffic Problems" on page 37).

Reduce Delay to Non-Crossing Traffic

Without specifying exactly how the benefits would be achieved, it is assumed here that some traffic movements could be facilitated that are currently blocked. Signal phasing and variable message signs might be used to help local traffic move around queues waiting to use the grade crossing. Table 38 lists the intersections near the grade crossing, out to Jericho Turnpike and Stratford Avenue, including traffic volume, turning movements, and distance to the crossing.

Table 39 continues the previous table to estimate hours per day that each intersection is, on average, subject to backup from the grade crossing. The "minimum duration" is

Table 38. Traffic movements in the vicinity of the grade crossing.

Street Intersection	with	AADT	Distance to RRX (feet)	Traffic Signal?	Legs	percent non-RR moves	average hour K-factor	one-way hourly flow (veh/hr)	2-way hourly capacity
NHP Road	LIRR	18,000	0	GC			0.062	588	4,000
2nd Avenue	NHP Road	500	50	N	3	67%	0.10	25	
3rd Avenue	NHP Road	500	50	N	3	67%	0.10	25	
Clinch/Greenridge Avenue	NHP Road	3,000	90	N	5	80%	0.10	150	800
Plaza Avenue	NHP Road	1,500	250	N	4	75%	0.10	75	
4th Avenue	NHP Road	800	490	N	3	67%	0.10	40	
South Park Place	NHP Road	500	510	N	3	67%	0.10	25	
Lincoln St. at Clinch Avenue	Clinch Avenue	800	550	N	3	67%	0.10	40	
5th Avenue	NHP Road	800	600	N	3	67%	0.10	40	
Jericho Turnpike	NHP Road	25,000	840	Y	4	75%	0.10	1,250	
Jackson St at Clinch Avenue	Clinch Avenue	800	900	N	3	67%	0.10	40	

the lowest combination of gate down time plus dissipation time that will allow the tail of the queue to reach the intersection. The amount of time that this duration is exceeded is taken from the vehicle queueing models (which depend, in turn, on the train acceleration and deceleration models) and, hence, the daily traffic movements that could be affected at each intersection. This is done for both the base (fixed-distance warning, no transient gate protection) and the improved CWT cases. Daily time savings are annualized and valued in dollars, on the assumption that each movement saves 20 seconds. These benefits are hypothetical and not included in the BCA totals.

Table 39. Delay savings from traffic ITS measures.

			Base		CWT	
Street Intersection	with	minimum duration (min)	time exceeded (hrs/day)	moves delayed	time exceeded (hrs/day)	moves delayed
NHP Road	LIRR					
2nd Avenue	NHP Road	0.17	4.36	73	2.50	42
3rd Avenue	NHP Road	0.17	4.36	73	2.50	42
Clinch/Greenridge Avenue	NHP Road	0.31	4.36	523	2.50	300
Plaza Avenue	NHP Road	0.87	3.38	190	0.14	8
4th Avenue	NHP Road	1.70	1.51	40	0.02	0
South Park Place	NHP Road	1.77	0.60	10	0.02	0
Lincoln St. at Clinch Avenue	Clinch Avenue	2.30	0.60	16	0.02	0
5th Avenue	NHP Road	2.09	0.60	16	0.02	0
Jericho Turnpike	NHP Road	2.92	0.60	565	0.02	17
Jackson St at Clinch Avenue	Clinch Avenue	4.05	0.22	6	0.02	0
			Total	1,512		410
			Annual Delay Savings ($)	$ 70,258		$ 19,051
			savings per movement (sec)	20		

Other Strategies for Moving Blocked Traffic

Traffic emerging from Second Avenue (see Figure 19 on page 39) is often blocked by grade-crossing queues on New Hyde Park Road because Second Avenue enters NHP so close to the rail crossing. Also, northbound NHP traffic and traffic from Plaza Avenue east of NHP seeking to enter Plaza Avenue west of NHP can also be blocked by grade-crossing queues. Although drivers routinely leave space in these intersections to permit feasible movements, no signs saying “Do Not Block Intersection” are currently posted. Such signs would help remind drivers that not all vehicles need to cross the tracks.

References

Abraham, J., T. Datta, and S. Datta, "A Study of Surrogate Measures for Rail-Highway Crossing Accidents," prepared for TRB, Washington, DC, January 1997.

Alroth, Willar A., "Chapter 11. Highway-Rail Grade Crossings," in James L. Pline (ed.), *Traffic Control Devices Handbook*, Washington, DC: Institute of Transportation Engineers, 2001.

ALSTOM Signalling, Inc., "ELSIE Final Project Report," prepared for New York State Department of Transportation, Rochester, NY: Alstom, October 2001.

American Railway Engineering & Maintenance of Way Association, "Practical Guide to Railway Engineering," Landover, MD: American Railway Engineering & Maintenance of Way Association, 2003.

Austin, Ross D., and Jodi L. Carson, "An Alternative Accident Prediction Model for Highway-Rail Interfaces," *Accident Analysis and Prevention*, 34 (2001), pp. 31-42.

Bernhardt, Kristen L. Sanford, and Mark R. Virkler, "Improving the Identification, Analysis and Correction of High-Crash Locations," *ITE Journal* (2002), pp. 38-42.

Bolton & Menk, Inc., "Emergency Vehicle Preemption Speeds and Improves Delivery of Emergency Services" *By Design* (Newsletter), Mankato, MN: Bolton & Menk, Inc., Winter, 1996, pp. 1-3.

Bowman, Brian L., "The Effectiveness of Railroad Constant Warning Time Systems," *Transportation Research Record*, 1114 (1989), pp. 111-122.

Carlson, Paul J., and Kay Fitzpatrick, "Violations at Gated Highway-Railroad Grade Crossings," *Transportation Research Record*, 1692 (2000), pp. 66-73.

Carroll, Anya, Anthony Passera, and Ike Tingos, "Vehicle Proximity Alert System for Highway-Railroad Grade Crossings Prototype Research," prepared for Federal Railroad Administration, Cambridge, MA: US DOT/FRA, April 2001.

Carter, Mark, Timothy Luttrell, and Brandy Hicks, "Advanced Warning for Railroad Delays in San Antonio: Lessons Learned from the Metropolitan Model Deployment Initiative," Washington, DC: US DOT/ITS Joint Program Office, November 2000.

Coase, Ronald H., "The Problem of Social Cost," *Journal of Law and Economics*, 3, 1 (1960), pp. 1-44.

DeLeuw Cather & Company, "Subsystem Design Document for the Long Island Rail Road Intermodal Control System (LIRR ICS): Intelligent Traffic System (ITS)," Rochester, NY: DeLeuw Cather, November 1997.

DeLeuw Cather & Company, "Subsystem Requirements Specification for the Long Island Rail Road Intermodal Control System (LIRR ICS): Intelligent Traffic System (ITS)," Boston, MA: DeLeuw Cather, November 1997.

DeMarco, Peter, and Mac Daniel, "Two Elderly Women Killed by Train in North Andover," *The Boston Globe*, December 11, 2002, B6.

Estes, R. Mathew, and Lawrence R. Rilett, "Advanced Prediction of Train Arrival and Crossing Times at Highway-Railroad Grade Crossings," *Transportation*

Research Record, 1708 (2000), pp. 68-76.

Farr, Edwin H., “Rail-Highway Crossing Resource Allocation Procedure: User's Guide, 3rd Ed.,” Washington, DC: US DOT/FRA, August 1987.

Farr, Edwin H., and John S. Hitz, “Accident Severity Prediction Formula for Rail-Highway Crossings,” Washington, DC: US DOT/FRA, July 1984.

Farr, Edwin H., and John S. Hitz, “Effectiveness of Motorist Warning Devices at Rail-Highway Crossings,” Washington, DC: US DOT/FRA, July 1984.

Federal Highway Administration, “Guidance on Traffic Control Devices at Highway-Rail Grade Crossings,” Washington, DC: US DOT/FHWA, November 2002.

Federal Highway Administration, “Highway Economic Requirements System State Version,” Washington, DC: US DOT/FHWA, December 2003.

Federal Highway Administration, *Manual on Uniform Traffic Control Devices*, Millennium ed., Washington, DC: US DOT/FHWA, 2001.

Federal Highway Administration, “Manual on Uniform Traffic Control Devices for Streets and Highways,” Washington, DC: US DOT/FHWA, 2003.

Federal Highway Administration, “Railroad-Highway Grade Crossing Handbook,” Washington, DC: US DOT/FHWA, September 1986.

Federal Railroad Administration, “Department of Transportation Accident Prediction and Severity Formulas,” Washington, DC: US DOT/FRA, c. 2002.

Federal Railroad Administration, “Railroad Safety Statistics Annual Report,” Washington, DC: US DOT/FRA, 1997.

Federal Railroad Administration, “Reference Manual: GradeDec 2000 version 1.4,” Washington, DC: US DOT/FRA, October 2000.

Federal Railroad Administration, “Use of Locomotive Horns at Highway-Rail Grade Crossings; Proposed Rule: 49 CFR Parts 222 and 229,” *Federal Register* (2000).

Federal Railroad Administration, “User's Manual: GradeDec 2000 version 1.4,” Washington, DC: US DOT/FRA, October 2000.

Fitzpatrick, Kay, Richard T. Bartoskewitz, and Paul J. Carlson, “Demonstration of Automated Enforcement Systems at Selected Highway-Railroad Grade Crossings in Texas,” prepared for Texas Department of Transportation, College Station, TX: Texas Transportation Institute, October 1997.

General Railway Signal Corporation, *Elements of Railway Signaling*, Rochester, NY: GRS, 1979.

General Railway Signal Corporation, “Subsystem Design Document for the Long Island Rail Road Intermodal Control System (LIRR ICS): Automatic Train Control Subsystem (ATC),” Rochester, NY: GRS, October 1997.

General Railway Signal Corporation, “Subsystem Design Document for the Long Island Rail Road Intermodal Control System (LIRR ICS): Intelligent Grade Crossing Controller Subsystem (IGC),” Rochester, NY: GRS, November 1997.

General Railway Signal Corporation, “System Design Document for the Long Island Rail Road Intermodal Control System (LIRR ICS),” Rochester, NY: GRS, July 1997.

General Railway Signal Corporation, “System Requirements Specification for the LIRR Intermodal Control System,” Rochester, NY: GRS, May 1997.

Glauz, William D., and Douglas W. Harwood, “Chapter 3: Vehicles,” in James L.

Pline (ed.), *Traffic Engineering Handbook*, pp. 50-77, Washington, DC: Institute of Transportation Engineers, 1999.

Halkias, John A., and Laurence Blanchard, “Accident Causation Analysis at Railroad Crossings Protected by Gates,” *Transportation Research Record*, 1114 (1989), pp. 123-130.

Halkias, John A., and Ronald W. Eck, “Effectiveness of Constant-Warning-Time versus Fixed-Distance Warning Systems at Rail-Highway Grade Crossings,” *Transportation Research Record*, 1010 (1985), pp. 101-116.

Heathington, K. W., Daniel B. Fambro, and Stephen H. Richards, “Field Evaluation of a Four-Quadrant Gate System for Use at Railroad-Highway Grade Crossings,” Transportation Center, University of Tennessee, January 1989.

Hellman, Adrian, Anya Carroll, Michael Lee, and Marsha Haines, “Preliminary Evaluation of the School Street Four-Quadrant Gate Highway-Railroad Grade Crossing,” Cambridge, MA: US DOT/Volpe Center, August 2000.

Hoelscher, Jim, John Fayos, and Marc Viggiano, “ATLAS Automatic Train Control: The Next Generation Train Control System,” paper for APTA, Rochester, NY: General Railway Signal Corporation, June 1995.

Hutton, B. J., “Rail-Highway Grade Crossing Warning Devices Maintenance,” *Proceedings*: 1985 National Conference on Rail-Highway Safety, Kansas City, MO, July 1985.

Illinois Department of Transportation, “Pilot Study of Advisory On-Board Vehicle Warning Systems at Railroad Grade Crossings: Executive Summary,” Schaumburg, IL: Illinois DOT, August 1999.

Institute of Transportation Engineers, “Preemption of Traffic Signals at or near Railroad Grade Crossings with Active Warning Devices: A Recommended Practice,” Washington, DC: ITE, February 1997.

ITS Joint Program Office, “Intelligent Transportation Systems at Highway-Rail Intersections: A Cross-Cutting Study,” Washington, DC: US DOT/ITS Joint Program Office, December 2001.

Klein, Terry, Tina Morgan, and Adrienne Weiner, “Rail-Highway Crossing Safety: Fatal Crash and Demographic Descriptors,” Washington, DC: US DOT/NHTSA, November 1994.

Korve, Hans W., “Traffic Signal Operations Near Highway-Rail Grade Crossings,” *NCHRP Synthesis of Highway Practice 271*, Washington, DC: Transportation Research Board, 1999.

Lalani, Nazir, and ITE Pedestrian and Bicycle Task Force, “Alternative Treatments for At-Grade Pedestrian Crossings,” Washington, DC: Institute of Transportation Engineers, 2001.

Lawson, Tim W., David J. Lovell, and Carlos F. Daganzo, “Using Input-Output Diagram to Determine Spatial and Temporal Extents of a Queue Upstream of a Bottleneck,” *Transportation Research Record*, 1572 (1997), pp. 140-147.

Lee, Douglass B., Jr., “Benefit-Cost Evaluation of ITS Projects: San Antonio Life-Link (DRAFT),” prepared for FHWA/FTA Joint Program Office, Cambridge, MA: US DOT/Volpe Center, October 2000.

Maryland Mass Transit Administration and Sabra, Wang & Associates, “Second Train Coming Warning Sign Demonstration Project: Final Report,” prepared for Transit Cooperative Research Program, *TCRP Project A-5A(2)*, Baltimore: Transportation Research Board, February 2001.

Mather, R. A., “Inspection of Automatic Grade Crossing Signals in Oregon,” *Pro-*

ceedings: 1985 National Conference on Highway-Rail Safety, Kansas City, MO, July 1985, pp. 105-111.

Mathieu, R., “Raised Medians and Grade Crossing Safety,” *Proceedings*: 1993 National Conference on Highway-Rail Safety, St. Louis, MO, July 1993.

Meek, Colin, “Raising Alarm,” *Health Which?*, August 2002, <www.which.com>.

Mengert, Peter, “Rail-Highway Crossing Hazard Prediction Research Results,” Washington, DC: US DOT/FRA, March 1980.

Mironer, Mark, Michael Coltman, and Robert McCown, “Assessment of Risks for High-Speed Rail Grade Crossings on the Empire Corridor,” Washington, DC: US DOT/FRA, August 2000.

National Transportation Safety Board, “Highway Accident Report: Highway/Rail Grade Crossing Collision Near Sycamore, South Carolina, May 2, 1995,” Washington, DC: NTSB, March 1996.

National Transportation Safety Board, “Highway/Railroad Accident Report: Collision of Northeast Illinois Regional Commuter Railroad Corporation (METRA) Train and Transportation Joint Agreement School District 47/155 School Bus at Railroad/Highway Grade Crossing in Fox River Grove, Illinois, on October 25, 1995,” Washington, DC: NTSB, October 1996.

National Transportation Safety Board, “Safety at Passive Grade Crossings Volume 1: Analysis,” Washington, DC: NTSB, July 1998.

National Transportation Safety Board, “Safety at Passive Grade Crossings Volume 2: Case Studies,” Washington, DC: NTSB, July 1998.

Nelson, Eric J., and Darcy Bullock, “Impact Evaluation of Emergency Vehicle Preemption on Signalized Corridor Operation,” prepared for TRB, West Lafayette, IN: School of Civil Engineering, Purdue University, October 1999.

Oak Ridge National Laboratories, *1995 National Personal Travel Survey*, Washington, DC: US DOT/BTS, 1997.

Parsons Brinckerhof Quade & Douglas, Inc., Inc. Zeta-Tech Associates, “An Examination of the Costs and Business Benefits of Positive Train Control,” prepared for Federal Railroad Administration, Boston, MA: PBQ&D, October 1997.

PB Farradyne, “Final Report for the Second Train Warning Sign Demonstration Project on the Los Angeles Metro Blue Line,” prepared for Los Angeles County Metropolitan Transportation Authority, Washington, DC: US DOT/FTA, January 2002.

Polk, Amy Ellen, “The Use of ITS to Improve Safety and Mobility at Highway-Rail Grade Crossings,” meetings of the California Public Utilities Commission, San Diego, CA, Washington, DC: Jet Propulsion Laboratory, August 2001 (www.nawgits.com/icdn/its_hri.html).

Richards, Stephen H., and K. W. Heathington, “Assessment of Warning Time Needs at Railroad-Highway Grade Crossings with Active Traffic Control,” *Transportation Research Record*, 1254 (1990), pp. 72-84.

Science Applications International Corporation, “Advanced Warning for Railroad Delays in San Antonio: Lessons Learned from the Metropolitan Model Deployment Initiative,” prepared for US DOT/ITS Joint Program Office, McLean, VA: SAIC, undated c. 2000.

SRF Consulting Group, “In-Vehicle Signing for School Buses at Railroad-Highway Grade Crossings: Evaluation Report,” prepared for Minnesota Department of Transportation, Minneapolis, MN: MinnDOT, August 1998.

SRF Consulting Group, “Moorhead Area Integrated Train Detection and Traffic Control System: Phase One Project Report," prepared for Minnesota Department of Transportation, Minneapolis, MN: MinnDOT, December 2000.

Taggart, R. C., P. Lauria, G. Groat, C. Rees, and A. Brick-Turin, "Evaluating Grade-Separated Rail and Highway Crossing Alternatives," *NCHRP Report 288*, Washington, DC: Transportation Research Board, 1987.

Texas Transportation Institute, "Traffic Violations at Gated Highway-Railroad Crossings," College Station, TX: TTI, 1997.

Transportation Research Board, "Traffic Control Devices and Rail-Highway Grade Crossings," *Transportation Research Record 1114*, Washington, DC: Transportation Research Board, 1987.

U.S. Department of Transportation, "The Value of Saving Travel Time: Departmental Guidance for Conducting Economic Evaluations," Washington, DC: US DOT/OST, April 9 1997.

Venglar, Steven P., Marc S. Jacobson, Srinivasa R. Sunkari, Roelof J. Engelbrecht, and Thomas Urbanik II, "Guide for Traffic Signal Preemption Near Railroad Grade Crossing," prepared for Texas Department of Transportation, College Station, TX: Texas Transportation Institute, September 2000.